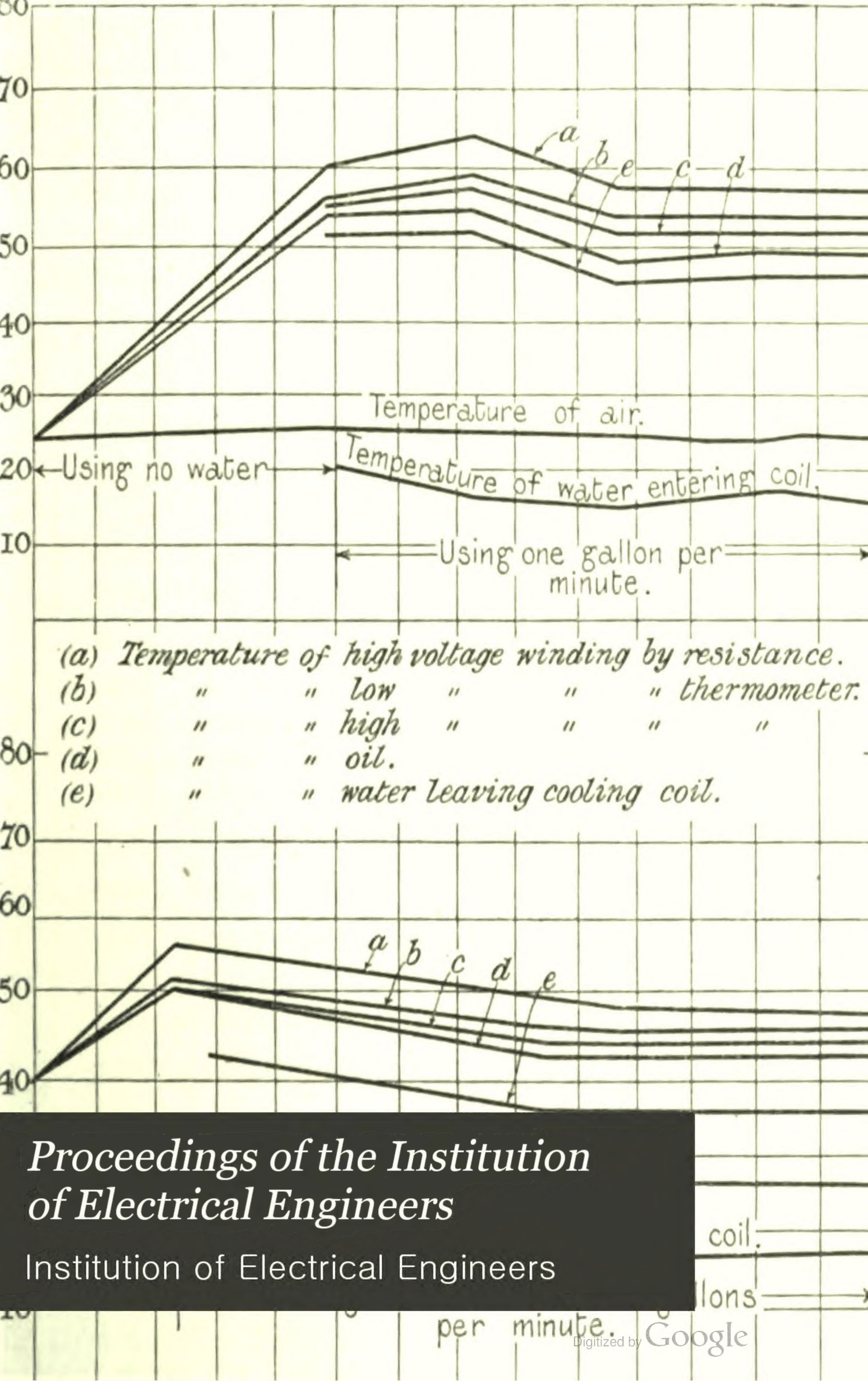


Proceedings of the Institution of Electrical Engineers

Institution of Electrical Engineers

comp pl st 2

JOURNAL

OF THE

INSTITUTION OF

ELECTRICAL ENGINEERS,

ORIGINALLY

THE SOCIETY OF TELEGRAPH ENGINEERS.

FOUNDED 1871. INCORPORATED 1883.

EDITED BY P. F. ROWELL, SECRETARY.

VOL. 48. ~~1911-12.~~ 1912

E. AND F. N. SPON, LIMITED, 57, HAYMARKET, LONDON, S.W.

SPON AND CHAMBERLAIN, 123, LIBERTY STREET, NEW YORK.

1912

Prof. Henderson

CORRIGENDA.

Vol. 48, p. 537, line 15 : "per cycle" *should be* "per half cycle"

Vol. 48, p. 537, bottom line : "Constant applied potential difference" *should be* "Applied potential differences of values proportional to the frequency and"

Barksdale
Engineering

The Institution is not, as a body, responsible for the opinions expressed by individual authors or speakers.

TABLE OF CONTENTS.

VOL. 48.

No. 211. FEBRUARY, 1912. VOL. 48

JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

ORIGINALLY

THE SOCIETY OF TELEGRAPH ENGINEERS.

FOUNDED 1871. INCORPORATED 1883.

EDITED BY P. F. ROWELL, SECRETARY.

CONTENTS

E. AND F. N. SPON, LIMITED, 57, HAYMARKET, LONDON, S.W.

SPON AND CHAMBERLAIN, 123, LIBERTY STREET, NEW YORK.

PRICE FIVE SHILLINGS.

JOURNAL

OF

The Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 48.	1912.	NO. 211.

MANCHESTER LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN.

HIGHER EDUCATION: SOME VIEWS OF A TEACHER-EMPLOYER.

By WILLIAM CRAMP, M.Sc. (Tech.), Member.

ABSTRACT.

(*Address delivered October* 27, 1911.)

It has long been my intention, so soon as circumstances should permit, to suggest for your consideration certain questions, upon the the answers to which the future of our very nationhood depends. Of these questions I shall take now but two, namely, "What sort of higher education is best?" and "How can that type of education be given?"

I shall try to give such an answer to these questions as shall apply to all professions, though, for various reasons, I shall in the matter of examples confine myself to engineering.

At the outset it is well to clear the ground by defining what I intend to consider. Herbert Spencer* has already classified for us the activities which constitute human life, and from his divisions I shall select

* Essay on Education.

three as defining the proper scope of higher education. These three are, in Spencer's own words :—

1. Those activities which by securing the necessaries of life indirectly minister to self-preservation.
2. Those activities which are involved in the maintenance of proper social and political relations.
3. Those miscellaneous activities which fill up the leisure part of life, devoted to the gratification of the tastes and feelings.

It is obvious that, while higher education should have to do with all three divisions, it cannot attempt to cover them. It can but aim at initiation. But even so, it should inculcate all those qualities which we would have in a man who is about to start upon his serious life-work, not the least of which is the ability to make himself useful to his employers. It is largely because I know that our technical schools and universities are now producing men not in the fullest sense useful to their employers, that I am bringing the matter before this Institution. The recent serious attempt on the part of the Institution of Civil Engineers to focus current opinions of the education of an engineer has, I think, failed completely. It was indeed bound to fail for many reasons; but chiefly because, like courses at many colleges, it was confined to the first of my three divisions, which is, I think, exactly where modern teaching institutions differ from the older universities.

Modern higher education in practice, if not in theory, aims at producing a finished and specialised animal instead of a plastic, well-informed and broad-minded man. It aims at producing a sort of industrial bee instead of a rational being; and results in a type which, under given circumstances, is warranted to do the right thing, but which when new circumstances arise is either confused or helpless. The professions for which higher education specially caters, year by year become increasingly complex; so that the period of training for a specialist constantly becomes longer and more arduous. For this reason, in my opinion, it is no more possible to produce a useful specialist in turbines, wireless telegraphy, or any other branch of engineering at the age of twenty-one, than it is to produce a first-rate brain, ear, or eye specialist. The very idea of the latter would be regarded as ludicrous, but the former is often expected. It is this attitude which has resulted in a university curriculum that is superficial, crowded, and unsatisfactory, though it embraces only the first of our three divisions. And the problem that presents itself now is the rearrangement of the college course so that it shall be possible to deal with all three forms of activity without producing more congestion and superficiality.

This, I think, may be achieved by keeping two main objects in view. The first is the co-ordination and arrangement of the various paths leading from the infant school to the finishing school or university. The second is the proper planning of higher education, so that it is correlated with the succeeding paths in life.

Of the first object I shall have little to say, since it is engaging the attention of men far better versed in the subject than I am. But this I believe, that sooner or later we must cut a broad and clear road from the kindergarten to the various institutions for higher education. Some nations have already shown us how to do this, notably Germany. Of their experience we may make good use; and one attempt, perhaps the best attempt, to do this has been put forward by a member of this Institution, Dr. Robert Pohl.* Whether we approve of his scheme or not, we must at least admit that it forms a good starting-point for discussion, that it is conceived in a broad and unbiassed spirit, and that great care has been taken to avoid the mistakes of Prussia, and to retain whatever in our existing chaos has been found to be good.

Of the other object, I think myself not altogether unfitted to speak. If seven years climbing from apprentice to works' manager meant lost time in some directions, it also gave me magnificent opportunities of knowing what the ordinary workman thinks; and I well know how fit one feels for the study of geometry after sweeping out the shop. If eight years teaching led to a salary smaller than that of many a foreman it showed me at least the relationship between the academic teacher and his students; and when it became my turn to learn the verb "to employ" in its active voice, I had the unique opportunity of observing the careers of those very men whom I had actually helped to train. Such opportunities of observation are invaluable as showing the extent to which the training fits the man for the world; and I regret to say that the record is not too encouraging.

The first and most striking fact about the career of the average student I have recently tried to emphasise.† It is perhaps best summed up by a sentence in a letter to me from the late Professor Ayrton, dated April 19, 1902. I had written to Professor Ayrton complaining of the narrow scope of the Central Technical College course. In his reply he said, "The great difficulty about the third year men's training is our not knowing what branch of electrical engineering they are going to take up." Precisely! And I might add that, even if this were always known, it would not follow that it was the branch they were going to stick to. Indeed the most remarkable thing is the number of quite different positions almost every man has to fill before he settles down into his final special groove. As an employer, then, the first fault that I have to find with students is the narrowness of their field of vision, the inflexibility and too great specialisation of their knowledge. Employers do not want men who can only do *one* thing properly. Business is not built so as to provide a niche for every saint. On the contrary, men, having varied work to cope with, must be capable of dealing with those varieties. But what do we find? If a man is excellent as a draughtsman, he may lack scientific knowledge. If he can calculate accurately a new range of motors, he very likely lacks polish, culture, or

* *Education*, April 2, 1909. *Technical Journal*, July, 1910, p. 108.
† *Technical Journal*, vol. iv., No. 11, p. 53.

tact. If he has culture and polish, he often lacks all sense of business procedure. So I am going to ask that every man who leaves a technical college shall possess, first, a wider scientific knowledge, and, secondly, wider general culture. In short, we want men to have had with their scientific training that truest form of education which will give them what the late William James called "width of field of consciousness." Thus and thus only can they obtain with ripened experience that greatest asset to the community, *sound judgment* in all things.

I submit, then, that the first necessary reform is abandonment of any attempt at specialisation within the ordinary three years' college course. Indeed I believe the time has come when, in the case of engineering at the age of twenty-one, we ought hardly to expect even differentiation between electrical and mechanical engineers.

Specialisation should, I think, be provided for later, either by higher university training or by experience in the ordinary walks of life. Think how such a change in the curricula would simplify the whole problem of education! It would relieve the tension in primary and secondary schools enormously. It would produce the type of man that we, as employers, really need, and it is the only way, in my opinion, of providing the time required for that greater width of field of consciousness to which I have already referred.

Such a reform also would fit in perfectly with the scheme of education proposed by Dr. Pohl, for it would standardise a general curriculum in all technical schools and colleges throughout the country for the first three years of training, while higher training than this could be given at scholarship-aided centres. It is not necessary to elucidate a point which has already been dealt with so forcibly in the paper referred to; but it may be remarked that this scheme would accord well with the dovetailing between manufacturers and training colleges, so much insisted upon by Professor Ayrton in the report of the first Moseley Commission.

To crystallise these ideas let us suppose the varieties of training divided according to the general professions to which they are intended to lead, and during the ordinary three years of higher education let no specialisation by further subdivision be permitted.

Then we must ordinarily provide schools for Medicine, Law, Engineering, Architecture, Theology. There is, as far as each general course is concerned, no necessity whatever to distinguish between so-called "pure" and "technical."* The general course corresponding to each profession would be arranged so as to cover Spencer's three divisions. There would thus in each case be training in—

1. The science appropriate to the profession (Fach Kenntnis).
2. Social, political, and commercial relationships.
3. Language, literature, and art.

* Thus will one of the greatest modern bugbears be abolished. I refer to the stupid rivalry between the theoretical men and the practical men—so-called. The former plume themselves as members of a higher caste, and the latter as men of greater achievement. The result is melancholy but comic.

Each division should have its appropriate manual training and practical work.

Of the three divisions the first only is peculiar to the particular "Fach." Valuable advantage may be taken of the fact that the other two are common to all students by making sure that there is no subdivision according to "Fach," but rather the reverse. This will lead at once, and naturally, to salutary mind-widening results now non-existent except at the residential universities.

SECTION I.—THE SCIENCE APPROPRIATE TO THE PROFESSION.

This is the one section at present considered by day colleges. I have given reasons for my belief that it should be generalised and broadened, and I must now show how I think this can be done. My method is simple; it is by fusion, simultaneous teaching, and correlation of all the usual subjects.

As emphasising the necessity for linking up the hitherto separate sciences, I heard Professor Rutherford say when he received the Nobel prize for chemistry, that he could not imagine why it was given to him since he did not know a single word about chemistry And so it is with the work of Sir J. J. Thomson, Ostwald, Van't Hoff, Faraday, and other original workers. You cannot say to what division their work belongs. It touches physics, chemistry, applied science, mathematics in almost equal proportions; and it is successful because these men grasp the significance of the principles upon which all science (not one science) depends. To give this same grasp is, or should be, the object of this section of higher education.*

If such broad educational highways can be adopted they will be found to lead ultimately, on the one hand, to fundamental conceptions of the universe, and, on the other, to those limits of detail-knowledge which form the proper starting-point for true research. Under such a system a man not only learns to think, but to think imperially, or rather universally. In whatever region of science he is working he is measuring—always measuring. Always interpreting one physical phenomenon in terms of another—that is measurement. In every region he is at home: he knows the language, he has his lines of communication always open, he is ever connected with the neighbouring kingdom or colony. For him knowledge is an harmonious whole, a great federation, a united empire.

This is the very ideal of the teaching of science as I see it; that there shall be no watertight compartments, no separate "subjects." To give such teaching effectively there will have to be, I think, a vast change in the *personnel* of our colleges, at least as far as the elementary classes are concerned. The aristocratic exclusiveness of the "professor" must go; the democratic communism of the philosopher must supervene. Men who have a keen interest in teaching for teaching's sake must be sought for. Men who love to show an

* In the full paper an example showing the application of this method to engineering was given in some detail.

old truth in a new garment, who are never tired of presenting the old landscape from a new point of view. For enthusiasm and life in their work they must rely on these interests, and on a psychological and sympathetic interest in their students. They must be psychologists rather than research-fellows; and students of human nature rather than of some recondite detail of scientific enquiry.

Section II.

We turn now to the second section of my proposed general course which I have termed "training in social, political, and commercial relationships." It is necessary for me to make clear what I mean by practical work in this section. I regard as such any well-regulated function at which student rubs shoulder with student under conditions of control, voluntarily imposed and maintained. Thus a football match, the management of a rowing club, or a union debate are all included, and much that is purely physical must fall within the course. It is this section that produces manliness (so woefully lacking in many technical schools). It is this section which distinguishes the older from the more modern universities. But the older universities fail grievously in one direction, for while they develop manliness, they also develop (towards outsiders) that collection of characteristics called "side." Professor Hartog has provided me with an excellent definition of side, which, he says, "is the unnecessary expression of superiority at the improper time."

An examination of the constitution of the social side of one of the older universities shows it as a rigidly exclusive privileged community embedded in the nation, yet distinct from it.

Within this community there are two well-marked classes, viz., graduates and undergraduates. Connecting the two there is a certain amount of graded inter-communication, but either class is in itself almost a pure democracy, and both classes agree in regarding themselves as select and apart from the outer world.

Thus, as far as the undergraduate is concerned, the university appears as a socialised organism rather than as part of an organised socialism. Save certain small distinctions of "set" and intellect, all undergraduates for whatever profession preparing are equal and regarded as equal by their rulers. They eat together, live together (except as regards sleeping), work together, and play together. So long as a man does not step outside the conventional "good form," he is tolerated and has his rights. The result is a rounding and smoothing and removal of the burrs; a "fettling," so to speak, of the otherwise rough castings. No man can rise but by individual effort; and this "individualism" blended with a certain strong feeling of *esprit de corps*, of corporate life, of unconscious belief in community of interest, and of the necessity of continued action if the life is to be maintained, tends toward that sense of responsibility known as manliness. This sense, again, is greatly assisted by the knowledge that the product,

when fettled, is generally accepted; which knowledge in turn tends towards a belief in the product, and towards a certain faith in the infallibility of the University. Thus do self-reliance (which is part of "manliness"), and self-assurance (which is part of "side"), go to some extent hand-in-hand, so long as the university is an exclusive social organism.

While the common life at the university is to some extent restricted and narrow, in another sense it is wide and free. Short of the "Thou shalt nots" which come within the proctors' purview, it is open to a man to do largely as he pleases. He may get himself into debt or his "eight," or whatever else may attract him, without let or hindrance. He finds himself, in short, for the first time a tolerably free agent in a little democratic state, with little to restrain him but the opinion of those he selects for his fellows. This it is which leads to self-reliance, and incidentally produces that effect recorded by the housemaid after the incident in the kitchen, when she declared that "Oxford had made quite a man of Master Verdant."

In other ways also, the freedom accorded to undergraduates is extremely salutary, as, for instance, in the liberty as regards work and play. In the time-table for the Cambridge Mechanical Sciences Tripos, I find no set course for any day after 1 p.m. This does not mean, of course, that no work is to be done after that hour, but that such work is to be decided upon and arranged by the students themselves in conjunction with their tutors, and that physical and social exercises are to have their due place. In many colleges the trust implied is not misplaced, and with a little alteration of the general university tone almost all the colleges might rise to this level.

Generally, then, of life at the older universities we may say in Touchstonese: That in respect of itself it is a good life; but in respect that it is an easy life it is naught. In respect that it is democratic, I like it very well; but in respect that it is exclusive, it is a very vile life. Now in respect that it is in the university it pleases me well; but in respect it is not in the world it is harmful. As it is a social life, look you, it fits the youth well; but as there is no real independence in it, it goes much against the man.

Now nearly all the virtues of the older universities arise from the fact that the colleges are residential; but residential universities cannot be provided *ad infinitum*, nor would they be used if they were. Nearly all the faults arise from the autonomous and exclusive nature of the residential colleges, and their segregation from the multitude; but non-residential colleges cannot be exclusive or segregated, and very rarely are they autonomous. The problem, then, is how to retain the advantages of a non-residential college while adding the beneficial effects of :—

1. Freedom of action and individual responsibility (competition).
2. Corporate life and social responsibility (co-operation).

I suggest that in ordinary day colleges and technical schools the

first of these must be encouraged by the provision of a principal and staff who are in the best sense of the words men and gentlemen. Just as Arnold's influence permeated Rugby, so will the example of a courteous, refined, dignified, broad-minded and capable principal be reflected in staff and students.*

Yet in the selection of a college staff, how little note is taken of these things! "The most essential things of all lie in the personality of the teacher," says Sadler; and still either a university degree or original work is the chief reason for the selection of a teacher. Even among the teachers themselves, I am afraid there are not a few whose attitude of mind is expressed by that negro who said, "Oh Lawd, de cotton am so grassy, de work am so hard, and de sun am so hot, dat I b'lieve dis darky am called to preach."

I hold it to be absolutely essential for the student to feel that every member of the staff is utterly incapable of mean or dishonourable action. Imagine the moral effect of the following scene, which took place in a London college not long ago. The lecturer was in the middle of his lecture, and had turned his back for a moment, when peas were shot at him from a back bench. Turning quickly, he said, "How dare you behave like that! If it occurs again, I shall know how to deal with it." A few moments later, of course, it did occur again. The teacher turned, and, fixing his eye on a certain culprit, said, "All right, Mr. A., it is your turn now, but when the examination papers are corrected, it will be my turn to score." The insinuation is almost too mean to be credible. Compare this incident with the statement of the negro, Booker Washington,† who declares, "The older I grow, the more I am convinced that there is no education which one can get from books and costly apparatus equal to that which can be gotten from contact with great men and women."

Next in importance to choice of staff, is confidence in the student; which must be shown by the omission of unnecessary register signing, checking of hours, insistence on attendance, and general shepherding. Twice have I come into touch with large technical colleges in which, when the student had once entered at 9.30 a.m., he was not allowed to pass the janitor till 12.30 p.m. without a special permit from a lecturer; and there are many similar cases of irritating and irrational restraint.

I hold that to get a man to his college at least punctually is desirable, but to keep him there by force is a sorry comment on the attractiveness of the studies and the trustworthiness of the man.

I have already referred to the trust implied at Cambridge in the matter of hours. This, under proper influences, encourages men to teach themselves; and of all the objects of higher education, learning how to learn is one of the foremost. As an electrical engineer might say, We must have men with a high "*coefficient of self-instruction*."

Directly connected with individual responsibility is that subtle

* *Cf.* "Moral Instruction and Training in Schools," International Report, vol ii., p. 346.

† "Up from Slavery."

quality "initiative," than which none is more useful to employer and employed. It is a quality not very rare in young children, but it apparently fades with age, for it is very rare in men of twenty-one. The reason is not difficult to find. Frederick Harrison has laid his finger upon it in his autobiography. For he says: "The Commoners, in the main, seemed to me, somewhat raw lads, without interest in art, or knowledge of the world. I was regarded as eccentric, if not mad. At Oxford any one was 'mad' who had any sort of individual taste or was careless of the conventions." But initiative is the offspring of meditation, and only flourishes in untrammelled freedom, unhindered by form and convention. What wonder is it, then, that within the cold confines of public school and university, with their "good form" and set expressions, this glorious quality sickens and soon dies? Apart from all question of special knowledge, what wonder is it that our Army officers lack initiative, our business leaders lack initiative, our political leaders lack initiative, when from boyhood to manhood they are perpetually reminded that originality is *outré* and individuality "bad form"?

What shall we do, then, to be saved? One thing only it would seem is of any avail. Remove from the university course every influence that can stunt the mind. Give width and play and freedom to every legitimate leaning, and you shall see the initiative of the child blossom again in the man. Encourage suggestions, questions, modes of proof, independent reading and thought. Say to your men: "The laboratory will be open this afternoon for those who want to try any experiment on their own account," resolving, of course, for safety's sake, that you will be there too.

In his excellent book, "Up from Slavery," Booker T. Washington has given very cogent help in this matter. I cannot do better than quote one passage: "At Hampton it was a standing rule that, while the institution would be responsible for securing some one to pay the tuition for the students, the men and women themselves must provide for their own board, books, clothing, and room, wholly by work, or partly by work, and partly in cash. At Hampton, the student was constantly making the effort through the industries to help himself, and that very effort was of immense value in character building."

If some similar scheme involving effort on the part of the student to enable him to retain his opportunities could be devised for our colleges, we need never bewail the loss of initiative. I suggest as a possible plan for engineers that each year they should be required to have earned a stipulated part of their school fees by work during certain months in a recognised trade or shop. These earnings might, under a systematised arrangement with the employers, be honoured by the local technical school or university.

Corporate life and social responsibility is a less difficult matter to deal with. How it is gradually inculcated at the older universities is very well known. In debates, sports, hall, and even "wines" and other social functions, undergraduates of all professions are brought

into contact with each other. It is this which gives to the thoughtful man breadth and culture; it is this which we must in the newer non-residential universities replace and amplify. For the collision of varying minds the university union is the natural centre; and next to it in importance is the athletic union. In all non-residential colleges, then, these institutions should not merely be tolerated, they should be provided for and supported. Such importance do I attribute to this, that I would give ample time for union functions, and while making it compulsory for every student to belong to the unions, I would also compel the university authorities to provide proper accommodation and facilities both in ground (for sports) and in buildings.

It must be remembered that my second and third sections are to be common to all the students, and therefore the artificial barrier now existing between men taking different courses would naturally be destroyed, and a healthy interchange of opinions would result. This influence can be further strengthened by the provision of suitable common rooms for students and staff, and by the hearty encouragement of social functions. Part of the time which would be available from the alteration of the curriculum would be employed in furthering social ends, in vivid teaching of political economy, and in "systematic and practical instruction in social and economic questions," as Sadler puts it. For this purpose it is most desirable that all concerned in teaching should be closely in touch with some practical work. For as its ultimate exchange-value in terms of other commodities must very often be the measure of work done, so is it extremely desirable that even a would-be parson should not leave the university without some acquaintance with commercial machinery.

In this section there remains still a most difficult side of social education to be dealt with—I mean the moral side. For employers it is essential, if business morality is not to fall to the low level of some of our Continental neighbours, that their employés shall be capable of acting upon sound principles even against strong temptation. They must, as Canon Masterman says, "show a constant preference for the general good over personal interest."

Now, in a non-residential college "atmosphere" is almost out of the question, yet "tone" and a proper attitude of mind towards life in general must somehow be imparted. In this connection it is significant that in all the stages of Japanese education "morals" come first. In Western education they are hardly mentioned except in a whisper. Baron Kikuchi declares* "that the courage and devotion of the Japanese soldiers during the late war was, to a great extent, the result of systematic moral instruction and training." Surely among educated men none will deny that,† "In true education there must be the kindling power of faith in an ideal." Surely every one will admit that "Intellectual and moral discipline must combine in order to produce an alert and adaptive intelligence,

* "Moral Instruction in Schools," vol. 2, p. 344.
† Ibid., vol. 1, p. 17.

trained to concentrate its attention, to trace cause and effect with candour and courage, to weigh evidence and to draw just and accurate conclusions," and that "will-power, to be rightly used, needs the curb of principle." But despite these apparent truisms it seems that "In the great majority of day training colleges, including those attached to universities, the students have at present no access to voluntary classes . . . for the study of ethical principles." I cannot, in the time at my disposal, attempt to give even an outline of the various methods which have been recommended for the inculcation of right thinking and right conduct. But the one conclusion to which I am led by a consideration of that great report from which I have just quoted, is that the first care must be as regards the choice and training of the teaching staff, through whose influence and example the greatest effect will most naturally be produced. Here, then, again is an argument for rigid care in the selection of teachers, and for providing ample opportunities of intercourse between students and staff.

Much as I should like to add to these bare suggestions a recognised course in ethics, my courage fails me. For ethics without living faith is vain, and living faith introduces that religious controversy which the example of elementary education bids me to avoid at all costs.

SECTION III.

Of those activities which fill up, or should fill up, the leisure part of life, I have already mentioned some in Section II. Indeed, it is very hard to separate these two divisions; and if I do so, it is more for the sake of convenience than necessity. How, then, can a love for, and an interest in, nature, literature, and the fine arts be stimulated in the college student? The answer is very much as before, By the influence of great teachers acting upon a mass of colliding minds. I can see no other way. It is not sufficient to hang upon the college walls costly reproductions, nor to give free a little music weekly. But if literary and art societies have not only official sanction but official support, if in the writing of exercises and reports literary form is considered, much may be done, even at a day college.

I once had an experience in this direction, which seemed to me to bear wonderful fruit. At the Central Technical College it is customary for third year men to write reports of the experimental work they do. Professor Ayrton arranged that I should go through these reports with their authors as they were written. Among about 30 such students I found scarcely one with any real literary sense; while, on the other hand, grotesque sentences and blunders in spelling were very common. Having gone through one report with each man, I found that his faults were due for the most part to pure lack of cognisance, so that when the second report came to hand the difference was simply marvellous. The most curious part was that many of the students came from public schools, and some had even taken a degree at Cambridge. Many of them had had a good classical training, and would not have dreamed of committing in Latin the blunders which appeared in their English.

On several occasions I found that a student would automatically correct the faults of one of his English sentences if I asked him to try to put it into Latin.

Employers know only too well how often a man comes to them incapable of writing even an ordinary business letter. I give the above instance as an example, not only of the way in which such ignorance may be eliminated, but also as an elementary means of encouraging æsthetic taste.

In the same manner, to an intelligent teacher, opportunities occur almost daily of developing similar sensibilities. I do not see why even the colouring of a scientific diagram should be allowed to be crude, and there are many instances where artistic feeling has incidentally a very real commercial value. To electrical engineers the familiar instances of arc lamps, fittings, and even the shape of motors will occur at once. In this section, perhaps more than in any other, the effect of breaking down the division between students preparing for different professions would be felt. If the engineer, for instance, can only be brought to take an interest in the composition of pictures as the photographic chemist does, then he is also likely to consider the effect of a bridge in a landscape. If the would-be designer of dynamos has chatted to a budding architect at tea-time, he is less likely to make his next motor look like a hat-box.

To sum up then, I may give my answer to those questions with which I began, in a very short form.

The best higher education is that which prepares best for those three great kinds of activity that I have selected from Spencer's five.

The means for carrying this out are in my opinion these :—

1. The division of technical colleges and universities into two sections, viz., the general and the specialised.
2. The arrangement of a course suitable for each of the five great professions at every "general" college.
3. The course for each profession should embrace training in the the three sections, which correspond to the three forms of activity.
4. In order to give time for all three sections and to inculcate general principles thoroughly, the first section (which now occupies all the time) should be taught as broadly as possible.
5. As but few of the colleges can be residential, the second and third sections which embrace social and æsthetic activities must be specially provided for.
6. This special provision would take the form of (*a*) a most carefully selected principal and staff; (*b*) avoidance of unnecessary restraint; (*c*) an arrangement by which the student should know that he was dependent upon his own efforts to remain at college; (*d*) proper opportunities for

social intercourse, not only between student and student, but also between staff and student; (*e*) definite official encouragement of university unions, literary and debating societies, and æsthetic and athletic clubs.

I believe that even a day college organised on these lines would produce the man who is needed by the world and valued by employers. For the employer is crying out for men of bigger character and broader mind, and the parent is wondering why his son is an engineer but not a man. It seems to me that for the provision of such general training there is nothing indeed lacking but the will to organise, for the buildings and equipment exist and the money is at hand.

We have, in fact, followed too far into a deep and narrow valley the "will o' the wisp" of industrial science "subjects"; the descent was easy; to retrace our footsteps is impossible, but to climb again to the upper air where we may once more breathe with freedom "*hic labor hoc opus est.*"

DUBLIN LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN.

HEATING AND COOKING BY ELECTRICITY.

S. L. R. PRICE, Associate Member.

ABSTRACT.

(*Address delivered November* 9, 1911.)

Heating and cooking as a subject probably appeals to only a comparatively few people, except in a general sort of way. Anything of a revolutionary nature relating to the heating of our dwelling-rooms, or the preparation of our daily repasts, is at once looked upon with decided aversion, the housewife being the first, as a rule, to condemn any innovation as expensive, inefficient, and useless, usually on the sole ground that it is not in keeping with what she was taught by those responsible for her domestic education.

One finds it difficult to dissociate from one's mind the necessity of a blazing coal fire for the proper heating of a room, or the ordinary coal-fired kitchen range for the efficient roasting of a joint or for the proper carrying out of any other culinary operation. These are the methods which have been adopted from time immemorial, a feeling as to the correctness of them is inherent in our nature, and we find it difficult to break away from what has been so intimately associated with our daily lives from earliest childhood.

This may all seem somewhat wide of the subject, but my object is to emphasise the extremely disadvantageous position in which the electrical engineer who seriously wishes to push electricity for heating and cooking purposes finds himself placed. He has not only to contend against conservatism, but also strong sentiment, and this latter adversary alone would stand adamant against facts and figures of the most convincing description. Certain it is that in these more enlightened days the canvasser who tries to persuade a customer to invest in an electric radiator or oven need have no fear as to the possibility of being

hurried off to the stake as might have been the case a hundred or so years back, still he will have many severe trials to contend with. After he has fluently and at some length described the apparatus with all its advantages, the lady of the house will remark, "How wonderful! I always thought that electricity had no heat in it. Of course, it is very expensive, and in any case I should be afraid to let the maids use it." No one but the canvasser trying to sell electrical heating and cooking apparatus realises the formidable nature of the two great barriers set up by the last two remarks. The first of these can only be gradually made to disappear by the customers' enlightenment as to the proper application of electricity in these particular cases and its economic uses, but the solution of the second difficulty really rests to a large extent in the hands of the manufacturers. It is a great pity that municipalities possessing electric supply undertakings do not deal with the difficulty in a more enterprising way by opening up showrooms and enquiry offices in good central positions with a view to assisting the public in educating itself as to the various uses to which electricity may be put. It is true that there is a growing tendency now to assist the intending customer in this way, but the movement is very half-hearted. The showroom should be equipped with all the most modern electrical appliances, so that the attendant may be always in a position to demonstrate to any one desiring to know the very best that electricity can do in a domestic way. Naturally enough, people refrain somewhat from seeking information in the ordinary shops, as they feel that if they go in they are expected to buy something before coming out. As a result, many remain in ignorance who would be only too glad to avail themselves of the benefits of electricity if only they had some easy means open to them of finding out exactly what would suit their requirements without being forced into doing anything in the way of purchasing. Another great advantage of this showroom system is that the details of any particular requirement can be carefully investigated and expert advice given, so as to enable an intending purchaser to go into an electrical supply stores with a clear knowledge as to his requirements, or refrain from investment altogether. This latter alternative would, in many cases, be more satisfactory to the electricity supply manager who often finds himself in the uncomfortable position of having to furnish quarterly accounts for current consumed which he feels sure there will be trouble over, purely due to the customer having purchased what was wholly unsuitable, extravagant in the consumption of electricity, and probably only possessing a hazy knowledge as to its most efficient method of application. To the contractor who, once he has sold his goods, has done with the whole business, this does not so much appeal, but to the people who have to supply the electrical energy, and have, so to speak, to live with the purchaser afterwards, the importance of this is borne home in its fullest force.

Having thus briefly considered the general and commercial aspects of electric heating, we will now pass on to the more technical side of the question.

As a heating agent electricity has in general two distinct applications, namely, for the heating of dwelling-rooms, halls, etc., and for cooking purposes.

Heating of Rooms, etc.

Every one is, of course, familiar with the two distinct ways in which this may be effected, namely, by radiation or convection.

In the case of radiation, the heat, as you are all doubtless aware, is transmitted by means of the surrounding objects. It does not therefore directly heat the atmosphere, but merely affects actual objects standing in the direct path of the rays emitted from the source of heat.

All the surrounding objects, though continually absorbing heat, are at the same time acting as heaters of the atmosphere by contact which sets up convection currents which circulate throughout the space to be dealt with. It will therefore be observed that although the heat is given off by radiation it does most of the work required of it by convection. Of course, in the case of individuals moving about or sitting in front of a source of radiant heat, warmth is acquired directly by radiation; this, however, is neither the most efficient nor after all the pleasantest method of acquiring warmth. You have all at one time or another experienced the seductiveness of standing with your back to the fire on a cold day, and the corresponding discomfort on moving away from it, which, of course, is due to the heat acquired by close contact with the rays being rapidly extracted by the cold air into which you have moved. It would therefore seem only sensible to suppose that the best and most efficient method of heating would be one by means of which the air in the space to be heated is dealt with directly so that persons moving about within the area experience no unpleasant effects due to differences of temperature. Of course, this is arrived at eventually by radiation, but the process is an indirect one, and while the operation is in progress one has to heat oneself by getting into close range with the direct rays and put up with the discomfort of feeling chilly on moving away. The ordinary coal fire acts as an excellent means of promoting circulation in the lower portion of a room, for, due to the strong rush of hot air up the chimney, proportionally strong cross-draughts are created along the floor of the room, emanating from under doors, etc., and all converging towards the fireplace. This accounts for the draught at one's back so commonly experienced while sitting before a good big fire on a cold day.

The colder the weather outside, and the larger the fire, the greater the tendency to cross-draughts, unless the passages into which the doors open are well heated, though this of course does not dispose of window draughts due to the same action. It has been suggested that the best method of heating the dwelling-rooms of a house would be to have large heaters in the entrance-hall and passages and quite small fires in the dwelling-rooms, if any at all. The flue action caused

by the chimneys leading from the fireplaces in the various apartments would tend to draw in the hot air from the passages and halls, where it would mingle with the colder air in the rooms, producing a resultantly comfortable effect.

Theoretically, what is required is a tempered atmosphere with no heavy currents or draughts. If this is to be effected efficiently and quickly the air should be heated directly by convection, and the surface contact of the heater should be a maximum. Hot-water pipes ranged round the skirting-board of a room work admirably, or in the case of halls and passages hot-water radiators placed at intervals have been found to be efficacious, though in the latter case there is a tendency to produce flue action at the radiators, causing the heat to ascend more or less rapidly to the ceiling. The aim should always be so to design and arrange a heating system that the air brought into contact with the heater or heaters is a maximum, and the tendency to flue action a minimum. That is to say, heavy uprushes of hot air must be avoided, and gentle lateral currents of warm air promoted. The milder the heated air given off, the less the tendency to rise and the greater the tendency for it to be dispersed throughout the lower strata by means of the ever present cross-draughts. Although a steam or hot-water heating system enables one to approach very near to this ideal state of affairs, it is very costly to install, extremely sluggish in action due to the high specific heat of water, and offers no flexibility in the matter of arrangement. Once installed the arrangement must remain. On trial it may not be found to deal exactly with the problem as was expected, but alterations cannot be made without in most cases incurring considerable further outlay.

If electrically heated tubes or radiators be employed the difficulty is at once got over. Should one arrangement be found ineffective, then another can at once be tried without further expense or trouble, and so a proper disposition of the heaters arrived at, producing the desired effect.

The absence of the water makes the apparatus very sensitive in action, so that almost immediately it is switched on it commences to do effective work.

The fact I would particularly like to make clear is the hopelessness of adhering to the old method of trying to make one heater do the work of heating a room or passage of moderate dimensions. It may be calculated (and correctly) that a 1,000-watt heater is necessary to do the work of heating a certain room, but it must not be supposed that the work can be efficiently or rapidly carried out if the whole of the energy is to be expended at one point. It should be split into as many small units as possible. If radiant heat be desired, four 250-watt radiators distributed about the room would prove very much more effective than one of 1,000-watt capacity, or if convectors be adopted, the heating units might be made even more numerous and proportionately lower in consumption. If this were done the working cost would be considerably economised, and electric heating brought into keener

competition with the other methods more generally in use, even at the present prices of current. While at the Glasgow Electrical Exhibition last autumn the writer had an opportunity of studying the advantages of a system such as that just mentioned, namely, judicious distribution of small units instead of one large one.

The heaters were quite simple in construction, consisting merely of a single radiator lamp with a concave bright metal reflector, a butterfly clip being attached at the back for the purpose of clipping on to the leg of a table, or any other convenient place. The reflector could be twisted round to any angle so as to throw the heat rays in any desired direction. It seemed to me that with a matter of three or four of these placed in suitable positions in an ordinary sitting-room a maximum effect could be derived in a minimum time.

Such an arrangement should prove admirable in the case of reception-rooms intermittently used.

It has often been stated that a 4-lamp radiator will not heat up a room of the most moderate dimensions to a comfortable temperature in less than two or three hours. In some cases this may be quite true, but I am inclined to think it more often merely goes to show that the problem is not being properly tackled, and not that electric heating is a failure. It is not at all an uncommon thing for a consumer, who proposes to put electric heating to the test, to use as a gauge of its efficiency a thermometer, which is brought into requisition and hung in the centre of the room, while others who pride themselves on the possession of a more technical knowledge of the subject, choose the mantelpiece as the proper position for the thermometer, the radiator being placed in the fireplace. Now these, of course, are the most absurd conditions, but are unfortunately often made use of as an easy means of condemning electricity for heating.

In the first place, the fireplace is not necessarily the proper position for a radiator. It may, of course, be under certain conditions, but not necessarily. Then, being radiant heat the objects within its range absorb all the heat given off, and the air only derives its heat indirectly by contact with these objects. The thermometer on the mantelpiece therefore, or hanging in the centre of the room, depending on whether or no it happens to be in a draught, may never rise a single degree in an hour, while at the same time people sitting within the range of the heater may be deriving considerable warmth and comfort. In investigating the heating requirements of a room at least three or four thermometers should be employed and simultaneous readings taken with a view to locating draughts and hot-air currents.

The 4-lamp radiator giving off 3,400-heat units cannot, of course, hope to compete in generosity with the average coal fire, which sends out into the room anything in the region of 10,000 heat units, this being only a small proportion of those which go to keep the jackdaw's feet warm ; but what can be said for the radiator is that every single heat unit emitted can be used efficiently and with an even unvarying result.

The following results were obtained from tests with a 4-lamp

radiator consuming 1,000 watts, in a room of moderate size, with one window measuring 5 ft. × 5 ft. and one door, both shut :—

		°F.
Temperature at 7.45 p.m.	... ...	54·0
„ 8.0 „	... ...	53·6
„ 8.15 „	... ...	53·0
„ 8.30 „	... ...	52·6
(Radiator switched on.)		
„ 9.0 „	... ...	55·4
„ 9.30 „	... ...	56·0
„ 9.45 „	... ...	56·4
„ 10.0 „	... ...	57·0
„ 10.15 „	... ...	57·4
„ 10.30 „	... ...	57·6

Current cost at 1d. per unit = 2d.
Temperature in passage outside room at end of test = 52° F.
Temperature outside windows at end of test = 45° F.
The radiator stood on hearthrug throughout test.

Who has not experienced the comfort of sitting down before a roaring fire to the pleasure of a book and the extreme discomfort of being roused to the chilly fact an hour or so afterwards that the fire has died out? Not so with the radiator, which having once been placed in a suitable position not only leaves one free of care in the matter of stoking, but gives an unvarying result, not obtainable with the same degree of nicety by any other means. Take the case of a man who has occasion to make use of his study for a couple of hours each evening, and that for half the year artificial heat is required, a 500-watt radiator placed beside him exactly meets his requirements, the cost at 1d. per unit (a very common charge for heating current per unit) working out at only 30s. 5d.

I estimate that to do the same work with coal 6 lbs. per hour would be required, which at 24s. per ton would work out at 23s. 5d. When the trouble of lighting and cleaning up every day has been taken into consideration I think the radiator would be well worth the extra 7s. per annum.

I next give the result of a test made on 9 lbs. of best house coal at 24s. per ton :—

		°F.
Fire lighted at 7.40 a.m., temperature in room	...	45·2
At 8.0 „ „	...	47·0
„ 8.10 „ „	...	49·0
„ 8.15 „ „	...	50·0
„ 8.20 „ „	...	50·4
„ 8.25 „ „	...	50·8
„ 8.30 „ „	...	51·0

					°F.
At	8.35 a.m. temperature in room			...	51·4
„	8.40	„	„	...	51·6
„	8.45	„	„	...	51·8
„	8.50	„	„	...	52·0
„	8.55	„	„	...	52·4
„	9.0	„	„	...	52·5
„	9.10	„	„	...	52·6
„	9.20	„	„	...	52·8

Outside temperature at start = 37° F.
Outside temperature at finish = 41·5° F.
Fuel cost (including 0·1d. for wood) = 1·25d. or 1¼d.

In comparing the results in the two cases above mentioned it must be borne in mind that the outside temperature fell 5° in the first case, whereas it rose 4½° in the second. The rooms in both cases had two outside walls and two inside walls with approximately the same window areas.

I may say that during the past couple of years I have used a 500-watt radiator for this particular purpose, and have quite satisfied myself that nothing else would so exactly meet the particular case.

Manufacturers have not yet realised the flexibility of electric heating, that is to say, how readily it can be varied in its application to meet varying conditions. From an artistic standpoint they have certainly been busy, for the variety of designs offered to the public is innumerable, but when one comes to look at the question from a heating engineer's standpoint advancement seems slow. Either a cluster of lamps, or a group of coils in an artistically designed case, is all we have to offer the public. Neither arrangement lends itself to the proper distribution of heat, and both are only applicable in a very limited number of cases.

Electric Cooking.

Electric cooking has made great strides during recent years, but there is still a good deal to be accomplished before it can be said to have surpassed all other methods of cooking for general domestic work, both from a practical and a financial standpoint. Perhaps the greatest stumbling-block to this complex problem is the hot-water question. How is the house to be supplied with hot water if the kitchen range is done away with? The answer to this is that any attempt at an electrical solution should be put aside for the present, as it only acts as a hindrance in the solving of the problem of electric cooking proper; not only that, but the question should be effectively disposed of by some efficient means other than electric, and at the same time, other than the present arrangement, which is in many ways just as bad as the electric method.

The figures given in the following table give some approximation of the hot-water requirements in dwelling-houses:—

	Temperature of Water.		
	100° F.	125° F.	150° F.
	Gallons.	Gallons.	Gallons.
For a bath	50	33·3	25·0
For each tap for washing purposes in flats	5	3·3	2·5
For each tap for washing purposes in hotels	20	13·2	10·0
For a lavatory basin	5	3·3	2·5
For a shower bath	9	6·0	4·5

It will be observed that the average hot-water demand per day in a medium suburban villa represents about 44,000 thermal units, that is to say, about 110 gallons at 100° F.

If electrical boiling apparatus with an efficiency of even 90 per cent. be employed the cost for current at 1d. per unit would amount to 1s. 2·37d. per day.

It is, of course, possible that some thermal storage system may eventually solve the problem electrically, electrical energy being supplied at a contract price per annum, but look at it what way one may, one cannot shut one's eyes to works costs and cut prices indefinitely, even if customers are kind enough to flatten out the characteristic of their demand. The consumption of hot water already given would require that the rate of charge should not be more than ¼d. per unit for heating purposes in order to compete favourably with other methods.

Of 221 municipal electric supply undertakings given in the *Electrical Times* tables of costs there is not one that has a total works costs as low as ¼d. per unit, and only one that approaches it (the total costs being 0·33d.). On the other hand, 133, or over 50 per cent., are over 1d. per unit. Supposing that any of these undertakings decided to supply for heating purposes at ¼d. per unit on the "dumping" principle, and that as a result electric heating became really popular in the particular districts, they would find themselves in the awkward predicament of selling the greater percentage of their output at considerably below works costs, and also of having to face large additional capital charges for extension of mains.

The coal-fired kitchen range has three functions to perform, namely, to heat side ovens, to do cooking work on the top of the range, and

to heat water at the back for the hot-water system. These functions cannot all be performed simultaneously with any degree of efficiency. As soon as the fire is lighted in the early morning breakfast has to be cooked, for which operation the oven dampers are drawn for the purpose of obtaining top heat for boiling or frying, and oven heat for warming plates, etc., with the result that the back or boiler heat is negligible and it is impossible to get more than one decent hot bath at most.

Hot-water systems should be dealt with quite separately. Enclosed coke-fired boilers are extremely efficient, and there are a number of good designs on the market. The initial cost of installation is quite moderate and the working cost low. A heating capacity of, say, 50 gallons per hour at 100° F. would be quite large enough to deal with the ordinary suburban 10-room villa and would cost about 2d. per day to run.

Having effectively disposed of the hot-water question, one is left free to deal with the cooking problem in the cheapest and most efficient manner.

Instead of having a kitchen fire burning from about 6.30 a.m. to 9.30 p.m. and consuming about 6 lbs. of coal per hour to deal with three meals at a cost of about 9d. per day, the various operations of roasting, boiling, washing, etc., would be performed individually as required by electric means, each unit being switched on or off as required. With electricity at 1d. per unit it has been proved over and over again by actual trial that an ordinary three-course dinner for half a dozen people should not cost more than 3d. to cook, breakfast 1½d., lunch and afternoon tea 1½d., making a total of 8d. per day, including 2d. for a supply of 110 gallons of water at about 100° F., which should suffice for a couple of baths at least, and general washing-up work.

The following comparative tests between a coal and an electric oven were witnessed by me and can be vouched for :—

9 *lbs. Roast Beef*:—

Coal oven took 2 hours, 20 minutes.
Electric oven, 1 hour, 40 „

2 *lbs. Sultana Cake*:—

Coal oven took 1 hour, 30 minutes.
Electric oven, 1 „ 10 „

4 *lbs. Fruit Cake*:—

Coal oven took 2 hours, 30 minutes.
Electric oven, 1 hour, 50 „

Until recently electric ovens have been too flimsily constructed to be of real commercial value. What is wanted is something that will stand the rough usage of the ordinary domestic servant.

The lagging will require to be improved, and the "Thermos" principle might with advantage be employed. Those that rely entirely on a polished surface to keep in the heat may be more or less sound in theory but are not so satisfactory in practice. If they could be kept clear of draughts they would be all right, but as in everyday practice this is impossible, a good deal of heat must be lost. I am inclined to think that a polished surface combined with lagging would give good results.

As to the pots and pans, etc., self-contained utensils will never do. It stands to reason that things of this sort which are constantly being scrubbed and rinsed under the tap would never last any length of time if they were self-contained. The hot plate must be the solution, but not altogether the arrangement at present on the market. It must be capable of taking ordinary utensils, such as may be bought at any hardware shop, and not specially made with planed bottoms, and yet it must have as high an efficiency as self-contained utensils.

In the case of an oven with air lagging a very interesting feature was observed about the heating curve, namely, that after the current had been on for 5 minutes the rate at which the heat built up in the oven fell off for a matter of a further 5 minutes, after which time it continued its characteristic. The same thing happened during the cooling down. It has occurred to me that this effect may have been due to the nature of the lagging. The curve obtained from an oven with silicate lagging and internal side flues shows slower heating up. The cooling down, too, is somewhat slower. In the case of an oven relying entirely on a polished surface for lagging and fitted with top and bottom heaters the heating up was very rapid, but the cooling down proportionately so.

A test on a polished saucepan showed the efficiency to be 80·9 per cent., and in a similar test on a stoneware electric jug the efficiency was 79·6 per cent. The latter is specially interesting, as although quite up to the average in the matter of efficiency it is also very cheap. This is certainly a move in the right direction.

A special type of oven is that in which the heating element is placed in the centre of the oven, an arrangement which is claimed to give a more even distribution of heat than when the heating element is placed at the bottom or sides. The automatic baster is also an ingenious device, obviating the necessity for constantly opening the oven, which invariably results in loss of heat with its consequent culinary troubles.

Before concluding these remarks it may be interesting just to glance at a few gas figures so that we may see what electric cooking has to compete against.

A test was made with a 1 pint bright tin-plate saucepan over a small gas ring, the result showing that 1 pint of water took 0·55 of a cubic foot.

Taking the value of the gas in British thermal units as 500 per cubic foot, the efficiency works out at only 69 per cent., whereas most

electric appliances for boiling give an efficiency of 80 per cent. at least, and many are considerably higher.

Taking gas at 3s. the actual cost of boiling one pint of water was 0·019d.—say 0·02d.

Taking an electric kettle with an efficiency of 85 per cent. the cost of boiling 1 pint of water at 1d. per unit works out at 0·06d. According therefore to test figures gas works out three times cheaper than electricity (a somewhat alarming figure at the first glance), but when wastage has been taken into account and the fact that ideal results are seldom obtainable with the ordinary gas range in everyday work, the results are not so alarming. Unless the admixture of air and gas is exactly right the efficiency will fall enormously—in fact, when everyday conditions are taken into account the difference in cost between gas and electric cooking will be found to be very slight, and when to electric cooking has been added the additional advantages of convenience, cleanliness, and general adaptability from an economic standpoint there can be no doubt as to its advantages over gas.

SCOTTISH LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

FRANK A. NEWINGTON, Member.

(*Address delivered November* 14, 1911.)

I have to thank you for the honour you have done me in electing me your Chairman for the present session, more particularly as this is the first session since the Glasgow Local Section has been enlarged into the Scottish Section. For myself, and, I think, all the members of the Institution resident in Scotland who were not attached to the Glasgow Section, I very gladly take this opportunity of thanking the Glasgow Local Section for the broad-minded and unselfish spirit which led up to the widening of the boundaries of the Section; and I sincerely hope that this widening will be the means of largely increasing the membership and usefulness of the Institution.

I am sorry I am not able to speak from personal use about the more recent developments in electrical generating machinery for public supply, as these have been almost entirely for multi-phase work, whereas in Edinburgh up to the present, and probably for some years to come yet, the direct-current system will be sufficient to meet all the requirements for energy.

The direct-current system of generation for limited areas has advantages of simplicity and economy, but on account of commutation troubles with large units at high speeds, it seems evident that all development on a large scale, in the immediate future at any rate, will be carried out by means of high-voltage alternating-current plant. At present the largest practicable unit of direct-current generator for high speed seems to be about 1,200 to 1,500 k.w., and even with this output, which is small compared with that obtainable from alternators, the commutators require very careful attention.

Perhaps a short description of some plant which was installed at one of the Edinburgh generating stations a few years ago may be of interest. This consists of two exhaust steam turbines, each driving a continuous-current dynamo of 1,200 k.w. Each turbine and generator at full load uses 45,600 lbs. of steam per hour at atmospheric pressure at the inlet with $27\frac{1}{2}$ in. vacuum. That is, the steam used previously by 1,560 k.w. of the reciprocating plant exhausting to

atmosphere now gives an additional 1,200 k.w. by means of these turbo-generators and condensation, so that for the same quantity of steam used the output has been increased by 77 per cent.

These two sets are enough to deal with all the steam used by the reciprocating engines during eight months of the year, but during the four winter months part of the steam from the reciprocating sets at the time of maximum load goes direct to the condensers, so that we are not using all the steam to the best advantage. The comparison of twelve months' figures before and after this plant was put down shows the following savings :—

Coal	22 per cent.
Water	54 "
Oil, stores, etc.	

The water for condensation is taken from one of the City main sewers which is about 180 yards from the generating station. There have been difficulties in designing efficient straining apparatus, but the scheme has proved an entire success.

In generating stations where the reciprocating plant is fairly new, the addition of exhaust steam turbines seems a very suitable way of much improving the economy of the existing plant as well as increasing the output.

On account of the introduction of the metal filament lamp the last three or four years have been an anxious time for both supply undertakings and machinery manufacturers, as on account of its great efficiency outputs have been decreasing or at the best remaining stationary, and consequently extensions of plant have not been required. Those undertakings that chiefly supply electricity for light, especially with alternating current, have had a great difficulty to make ends meet, but in only a few cases has it been found necessary to increase the price. In the majority of places, however, the corner seems to have been turned, and it may now be expected that the greatly increased efficiency of the metal filament lamp will lead to a considerable increase of users. This lamp has been very considerably improved in durability, but the filaments of most makes are still very fragile, and the lamps require handling with care. Without taking any account of the advantages of cleanliness, pure atmosphere, and convenience, the metal filament lamp is now quite able to compete with the incandescent gas mantle with electricity at 2¾d. per unit and gas at about 3s. per 1,000 cub. ft., but at present in most of the electricity supply undertakings the rate for electricity for lighting is above this figure.

From the number of firms who are now making metal filament lamps it seems that it must be a profitable business. Competition, however, will probably tend to reduce prices considerably, and then the supply undertakings will begin to reap the benefit by a considerable increase in lamp connections. The present price of 3s. for a metal

filament lamp frightens the small user when he can get a gas mantle for 5d.

Makers of metal filament lamps have for a long time been trying to produce lamps of about 16 c.p. for voltages of from 200 to 250, and lamps of this size can now be obtained. But are these small candle-power lamps really wanted? The standard of illumination has very much increased, and one 16-c.p. lamp is now not sufficient for lighting even a small room. The keen competitor to the metal filament lamp is the incandescent gas lamp of about 60 c.p., when the mantle is new, and I cannot help thinking that the makers of metal filament lamps would be serving their own interests and those of the supply undertakings better by devoting themselves to improving the higher candle-power lamps—that is, from 30 c.p. upwards—and in reducing the price as much as possible. The fewer sizes of lamps made, the greater number of each size will be required, and therefore they can be made more cheaply.

The majority of towns in this country are not large manufacturing centres, and therefore the electricity supply undertaking must principally rely on lighting as a means of revenue. The small power user is, as a rule, an extremely short-hour consumer, probably averaging only 1½ to 2½ hours' use per day, and so not any better than the average user for light. Take the printing trade, for instance, which is a large industry in Edinburgh, chiefly consisting of works averaging about 20 H.P. We find that their average use is only 3½ hours per day of their maximum demand, and unfortunately their busiest season is in December, that is, just at the time of maximum load for lighting. It is very doubtful whether this class of power user is a profitable one with electricity at about 1d. per unit, and in a large number of towns, not chiefly manufacturing, it would probably be advantageous to the supply authorities to reduce the rates for lighting rather than to supply for power at very low rates. It may be said that the maximum demand system should get over this difficulty, but apparently it does not. It is unpopular with the users and is being discontinued in a number of places.

In order, however, to give the long-hour power user a preference we have in Edinburgh this year adopted this system in a modified way, so that all consumers who use their motors for more than 3½ hours per day will be entitled to reduced rates ranging from 1⅛d. per unit for a 3½-hour user to—

0·8d. per unit for an 8-hour user.

As only a comparatively small number of consumers will benefit by this scale it will not be difficult to explain to them how the rate is arrived at.

In large manufacturing towns such as Glasgow and Manchester the conditions are quite different, and in such places power in large quantities can be supplied profitably at low rates. There has been a good deal said lately about encouraging industries by means

of a low rate for electricity for power, but ¾d. or even ½d. per unit will not make very much difference to the total expenses of small works; rates and taxes, building laws, price of land, and rates of labour will far outweigh cheap power.

To fix suitable rates of charge for all classes of users is an exceedingly difficult problem. The ideal system is that every user should pay what the supply to him has actually cost, plus a small profit, but it would be very difficult to arrive at this exact cost, and in many cases quite impossible to convince the consumer that the rate was correct. The maximum demand system has one very weak point, that is, it does not indicate the time at which the maximum load is used, so that a power user might be using the greatest quantity during daylight hours when the supply authority had plenty of plant available, and yet the rate would be based on the record of the demand indicator. An instrument which would indicate the time at which the maximum was used would probably be prohibitive on account of expense.

A number of systems of charging have been introduced during the last few years with the object of benefiting the long-hour consumer. Some of these are based on the assessment or rental of the house, as at Norwich; others use a modification of the maximum demand. But most of these seem to be a somewhat roundabout way of arriving at the consumption, and probably will result in dissatisfaction to a large number of consumers.

In Glasgow Mr. Lackie has recently devised a scale of charges for electricity for heating and cooking for domestic consumers, which seems promising and is exceedingly simple. From previous records he is able to tell the average consumption for lighting of the various classes of consumers. This number of units is charged for at the lighting rate, and all beyond this at 1d. per unit. The extreme simplicity of this system is a very great advantage, especially as it does not require separate wiring for the heating circuits. It will be of great interest to know the result of this method of charging, and it is to be hoped that later on Mr. Lackie will be able to make this known to the Institution.

It must be admitted that heating and cooking by electricity are not making very rapid progress. Probably this is due partly to the high price of the apparatus and partly to the price of electricity. Even at 1d. a unit it is questionable whether an electric cooker can compete with a gas cooker. The makers of electric cookers, however, claim that owing to the ease of regulating the heat and the considerably less waste of the meat cooked, electricity at 1d. per unit is cheaper than gas. Electric cooking appliances have been considerably improved during the last few years, but there seems room for still further improvement. Probably the principal obstacle to their more general use is the high price. Small householders, at any rate, will not pay from £10 to £15 for an electric oven when they can hire a gas oven for 7s. a year. The hiring of cooking and heating appliances by electricity supply undertakings has met with a large amount of opposition from

electric wiring contractors, but this seems to be a short-sighted policy. Most of the gas undertakings hire out gas stoves and ovens, and undoubtedly without this the consumption of gas would have been very largely reduced. The electricity undertakings should be able to compete with the gas undertakings on equal terms. Probably it would not be profitable for wiring contractors to hire these appliances, as this requires a fair amount of capital, and only a small return can be expected. The manufacturers also do not seem inclined to do this. The position therefore is as follows: The consumer will not buy, but is prepared to hire. The supply authority cannot hire unless it has obtained special power to do so; the wiring contractors will not hire and do not want any one else to do so. Under these conditions it is not surprising that the use of electricity for heating and cooking is not making much headway. Personally I think it is better for the supply undertaking not to hire out these appliances if some one else will do so.

In fixing the rate of electricity for cooking, the following point must not be lost sight of. Except in very small houses, the greatest quantity of cooking is required for the evening meal between 6 and 7 p.m., so that the stoves will be in use at full heat between 4.30 and 5 p.m., that is, at the time of maximum demand for light in the winter months.

Our President in his most able and interesting address last session * dealt with the enormous waste of coal, practically our only raw material and our most valuable possession, which is going on at the present time. He showed how by generating electricity at the coalfields and distributing all over the country a saving of about 90 million tons of coal a year would be effected, that is, the coal used would be reduced from 150 million tons to 60 million tons a year. I am sure we all hope that his prophetic ideas may some day be realised, but as there is not far short of £100,000,000 sunk in electrical generating plant in this country it will probably be a long time before the owners of this plant will be able to scrap it. Meanwhile we are exporting annually about 90 million tons of coal, largely to enable foreign manufacturers to compete with us. Whether this free export of coal is wise or not is a very complicated question, but to me it seems rather suicidal.

Sir William Ramsay, in his presidential address to the British Association this year, also dealt with the coal supplies of this country, and stated that if the rate of coal-getting in the future increases as it has in the past, our coal will be completely exhausted in 175 years. This is, I believe, a very much shorter period than had previously been allowed. One hundred and seventy-five years seems a long time to any individual, but really is quite short in the life of a country. As coal is the only known natural source of energy in this country at present, any means of reducing waste is of the greatest importance.

From what information I have been able to obtain, most of the manufacturers of heavy electrical plant at the present moment seem to be extremely busy and working overtime, but on examining the share

* *Journal of the Institution of Electrical Engineers*, vol. 46, p. 6, 1911.

quotations as published in the electrical papers one cannot help wondering whether the work is remunerative, as, with the exception of the cable companies, all of whom seem to be in a flourishing condition, the majority of the ordinary shareholders have not been receiving any dividends for some years. This state of things will not encourage the public to invest their money in electrical manufacturing concerns and cannot be good for the industry. What is the cause? Apparently it is not due to foreign competition, as the value of electrical plant imported from abroad during last year was not very great—about £600,000 as against £12,000,000 to £13,000,000 manufactured in this country. It seems that the cause is the extremely low prices quoted by the home manufacturers. I think I am quite on the safe side in saying that large electrical plant can now be bought for one-fourth or less of what it cost ten to fifteen years ago. It has been said that this extreme cutting of prices has been caused by local authorities advertising for tenders and generally accepting the lowest; but, provided that the lowest offer is satisfactory and from a reliable firm, what else could be done? The local authority can but suppose that the price quoted allows for a sufficient profit. The real reason appears to be that the capacity of the existing works for turning out plant is far greater than the demand, and the only remedy seems to be a large increase in our trade abroad. A general understanding amongst manufacturers to increase prices probably would not be of any use, as this would at once result in competition from abroad becoming much greater. Apparently the reason of the small quantity of electrical machinery imported into this country at the present time is the low scale of prices quoted by the home manufacturers, which is lower than foreign makers can compete against.

As a user and not a manufacturer of plant, I should like to say a word or two about prompt delivery by the date specified. Public supply undertakings must have sufficient plant to meet their maximum winter load, but on account of the capital charges, interest, and sinking fund, it is not advisable to install the plant many months before it is actually required; so if it is erected and running by the middle of the autumn this is soon enough for the winter load; but if the manufacturer is three or four months behind the specified time the consequences to the supply authority may be very serious, and any penalty for late delivery that may be exacted may be quite insufficient to make good the damages that may be incurred; for it must be remembered that a supply authority must maintain a sufficient supply of electricity, and any failure to do so may result in a heavy penalty for every day during which the supply is deficient. I think, therefore, that many local authorities would be prepared to pay a higher price provided that the work was completed by the specified time. A bonus for delivery before the specified time does not get over the difficulty, as the plant is not wanted before this date, and the buyer would then have to pay interest on capital before the plant became revenue-earning, as well as the bonus. Other things being equal, a manufacturer who could be

depended on for punctual delivery would certainly have preference over others who had got a reputation for unpunctuality.

The subject which is probably of the greatest interest at the present time to engineers and also the general public is the labour question. It is a difficult subject to deal with in an address of this kind, as unfortunately it has become a matter of party politics, but it may so seriously affect the welfare of the country that all moderate men—and, after all, I believe nine-tenths of the voters in this country would be moderate men were it not for a few firebrands who make an easy living by stirring up strife—should, I think, try to get to the bottom of the trouble. Undoubtedly there is an enormous amount of undeserved poverty in this country, and anything that can be done to lessen this is worthy of all praise. But this is not the cause of the recent strikes. The majority of railway and tramway servants are fairly well paid, the wages being considerably higher than a few years ago, but the working classes seem to have made up their minds that capitalists are taking too large a share of the profits and labour getting too little. The dividends of the railway companies are, I think, a sufficient answer to this. The working classes appear to have shut their eyes to some very important facts, probably the most important being foreign competition in trade. We as a nation depend entirely upon our manufactures and our trade with other countries, and if our scale of wage is higher, or, shall I say, our output per pound of wage is lower, under our present fiscal system we are seriously handicapped. Manufacturers are at their wits' end to find out how to meet foreign competition: apparently the working man knows or cares nothing about this.

Another point is that capitalists, whether large or small, will certainly try to get a fair return on their capital, and if they cannot invest it profitably in this country they will send it elsewhere, which of course means less employment of labour in this country.

One very serious phase of the recent strikes was the more or less complete stoppage of the electricity supply at Liverpool. Several of the supply stations in London also had to be guarded by the military. Under our present conditions of civilisation it is most essential for the streets of our towns to be well lighted, and it should not be possible for a small number of men to interfere with lighting or similar services which are necessary for the safety of the public. In 1875 the "Conspiracy and Protection of Property Act" made it a penal offence for any person employed in gas or water undertakings to break his contract of service, should such breach of contract interfere with the supply of gas or water. The date of this Act explains why electricity supply was not included. It is the duty of this Institution to get this Act amended to meet the requirements of the present time with the least possible delay.

The following is the only probable explanation of the labour question that I can think of. There is an old saying, "A little knowledge is a dangerous thing," and I believe the present system of superficial education is unfitting working men for the work they have to do and not

fitting them for anything higher. It is to be hoped that 20 or 30 years hence the faults in the present system of elementary education will have been rectified and that the working man will be better fitted for the work he has to do. Now, the method seems to be to coax lads to do what some years ago they were made to do, and the old parental authority seems to have largely disappeared. The Boy Scout movement is an instance of this. Without doubt it does a lot of good, and to some extent makes up for the loss of the discipline of former years, but it is humouring boys and making things pleasant for them. Will it make them better fitted to meet the stern realities and hardships of life? That which is worth learning is not easily learned.

Several papers on the training of engineers have recently been put before the Institution, but it is not of much use having a number of highly trained engineers to design work unless you have the workmen to carry out the designs. I hope, therefore, that you will accept this as my reason for dealing rather fully with a matter that may seem to have little connection with engineering. The labour question is one of the most important of the present day, and is being most anxiously considered by a large number of able men. Public opinion will, without doubt, in the course of time decide that these fierce struggles between the employers and the employed are most harmful to the welfare of the country, and methods will be devised for settling these disputes in a more reasonable way. Probably this much desired result is still a long way off, but if I have said anything to cause you to try to find some means of improving the present most unsatisfactory relations between employers and employed, I shall have done something.

YORKSHIRE LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

T. HARDING CHURTON, Member.

(*Address delivered November* 15, 1911.)

It is again my pleasant duty to address you at the opening of a session of this Section, and I thank you very much for the honour and distinction that you conferred upon me by re-electing me to the chair.

The session upon which we are now entering promises to be one of exceptional interest, and some excellent papers will be presented to you. I hope that as many as possible of our members and their friends will avail themselves of the opportunities that will be afforded for extending their knowledge and that they will themselves add to the value and interest of the papers by contributing to the discussions upon them. In this connection, may I remind members that copies of the papers to be read are usually available some days beforehand, and that it should add to the interest of the discussions if members would more generally, perhaps, than hitherto, read the papers through and think the matter over before the meetings.

The numerical strength of our Section has suffered through the transfer of a number of members to the Newcastle Section, the meetings of which they could more conveniently attend; but their loss to us—as they are still in the Institution—we have no cause to regret. Apart, however, from the numbers thus transferred, there is a slight falling off in our numbers; and though this is not at all serious, I would venture to impress upon all our members that it is to our advantage to make the Institution in general, and this Section in particular, as strong and representative in its membership as possible. The Council of the Institution, recognising that electricity is becoming more and more closely connected and associated with almost every form of industry, and that it thus claims the interest of a great many persons besides electrical engineers, has proposed to widen the borders of the Institution so as to embrace many such persons, who, though not by profession electrical engineers, are interested in the application of electricity.

For this purpose the classes of membership are to be slightly rearranged, and I hope that this, and the increased advantages that

membership of the Institution now affords, will result in a large accession to our numbers in the near future. Each one of us should make it his business to introduce our eligible friends and acquaintances to the meetings and to endeavour to secure their admission to the Institution.

This Institution has been not infrequently regarded, I believe, as a purely scientific and academic body, having little or no thought for matters connected with the trade or commerce of the industry. But though our work be chiefly concerned with scientific and technical subjects, we should not forget that for the realisation of the benefits of those discussions we depend upon trade. While we may keep our eyes on the stars we must remember that our feet are upon the ground. Electrical engineers carry on their business or profession for the purpose of making a living, and this Institution will flourish or not according to whether its members succeed in that essential (or primary) purpose or not. If, therefore, the advancement of the application of electrical science (to borrow the words of the Memorandum of Association) is hindered by economic or legislative causes that may be capable of being reduced or removed, it seems right that the Institution should do all that it fittingly can do to that end. The Institution of Electrical Engineers is, in fact, interested in the welfare of all sections of the electrical industry, and with the growth of its membership and influence is bound up, I believe, the future prosperity of the electrical industry in this country. And remembering that "in unity is strength," I hope to see close and effective co-operation between the Institution of Electrical Engineers and the various associations that have for their object the protection and advancement of the interests of their several branches of the industry.

The Labour Problem.

The state of unrest that has manifested itself in the unfortunate labour disputes of late, in consequence of which the electrical—in common with every other—industry has suffered, obliges us to consider what lies at the root of the trouble, and the principles that are involved.

The state of agitation to which I refer has undoubtedly originated in the ambition on the part of labour to participate in a larger share of the wealth produced. A "living wage" for the least efficient or productive labourer, and more than that for those whose work requires the exercise of more skill, is demanded. Unfortunately, in this, as in many other problems of political economy, the meaning is vague and is obscured by the use of terms to which no definite meaning can be attached in the absence of exact definitions—which are seldom given. What, for instance, is meant by a "living wage"? Essentially, it must be that which may be exchanged for—

1. Such an amount of food-stuff as may be required to replace the tissue expended in the act of performing the work, plus that expended in making good the constant losses (and which we

may liken to the constant losses in an electric motor that is kept running "idle" while the work is not required of it); and—

2. Protection against climatic conditions, whether clothing, fuel, or shelter.

These two items include all that is absolutely necessary to maintain the worker, and the "wages" that will procure them may therefore be called a "living wage." But that, clearly, is not the idea of the man who wishes to *enjoy* "living" as much as possible, and to be paid such a wage as will enable him to live up to his ideas.

It has been said that perhaps the chief characteristic that distinguishes mankind from the rest of the animal kingdom may be summed up in two words, "progressive desire." Whatever may be said of his desire to progress in other directions, it is at least easy to understand that he should desire to progress in his enjoyment of living. But let us consider some of the factors by which this is really regulated.

The production of any commodity requires first, and as a necessary antecedent—

1. Capital (which I would define as being the accumulation of the necessaries for existence or of anything for which they may be exchanged, or of things necessary or useful for the production of either), and—
2. Labour (by which I mean the exercise of physical work, or those, collectively, who are hired to perform it).

Without capital, every one would be obliged, as the wild animals, to seek their daily food. As soon as a man "A" began to save a stock of food he accumulated capital that enabled him to turn his attention to producing something else—say, for example, leather. The skins of the animals that he had killed for food, now that they can be turned to something that he can exchange for food, become part of his capital. And if our capitalist finds that people will give him for his leather much more food than he could get by himself, and he then offers to feed regularly from his store another man (whose food supply may be somewhat precarious) in return for which the man agrees to assist him to make more leather, then we have at once the position of capitalist-employer and labourer.

Similarly another man, "B," having accumulated sufficient food may collect and smelt iron and from it make tools. Another, "C," in like circumstances, may exchange some of his surplus food with "B" for some tools with which he may cut down trees and fashion the wood into tables and chairs.

Now, with a number of people in the community thus engaged in producing various commodities but not food, which, however, they are all the while consuming, it is clear that as a condition of their continuing in this course, they must be supplied with food by others who obtain or procure more than they themselves require, and which

surplus they are willing to exchange for the commodities produced by the "industrial" members of the community. Let us suppose that "D" having accumulated sufficient capital to keep him supplied with necessaries for several months, commences agriculture, and finds that he has thereby so far improved the conditions that favour the natural production of food that he is enabled to provide sufficient for a number of others. He is thus able to exchange some of it for tools with "B," tables and chairs with "C," and to offer to others a regular supply of necessaries in return for their labour.

The knowledge, skill, and enterprise that enabled and induced the capitalist "A" to turn the skins to useful account, "B" to make tools from the iron-ore, "C" to make (with the aid of tools) tables and chairs from trees, and "D" to facilitate and thus increase the food supply, was part of the "capital" of each—these attributes, or some of them, being essentially necessary for the production of necessaries for existence or of things for which they may be exchanged—and it was, in fact, the possession of them in a superior degree that enabled "A," "B," "C," and "D" to acquire their material capital. And it was these same qualities together with the material capital they had acquired that enabled the possessors of them to employ others who did not possess them in an equal degree. The result was that the labour was rendered more efficient by the guidance of the employer and the use of his capital, and, reciprocally, the capital (including the personal attributes) of the employer was rendered more efficient (*i.e.*, productive) by the labour employed. Thus, both the employer and employed were directly benefited by the co-operation.

It will, of course, be clear that the principle of exchange is precisely the same whether the commodities are directly exchanged for one another or money is employed as a convenient medium of exchange.

With all the complexity of the system in which we live, we depend as much as ever upon the food supply and are just as dependent upon the accumulation of capital to maintain the possibility of a civilised state as was the simple community we have considered.

The problem that we are investigating resolves itself, then, into this:—

What is it that regulates the proportion of the produce of the capital and labour employed which goes to the owners of the capital and to the labourers respectively?

The relative value in exchange of anything, be it capital or labour depends upon the law of supply and demand—that is to say, its value in exchange varies inversely as the supply of it and directly as the demand for it.

We are familiar with the fact that when there is a shortage in the supply of any commodity the price of it goes up, and, on the other hand, that when there is a plentiful supply of an article—say of plums, for example—the price goes down. For precisely the same reasons the value of labour of any particular kind depends upon the supply of, and the demand for, that particular kind of labour. We well know that

a man that can perform a certain kind of work for which there is a large demand, but which few can perform or can perform as well, is relatively highly paid for his services.

On the other hand, work that can be equally well done by a much greater number of persons, is paid for at a correspondingly lower rate.

Similarly with capital. The more that it is in request, the higher is the price that its use will command. The more capital there is in a country, the less must be the value of the use of it for a given amount of production in that country, and *vice versa*.

Now, in any particular part of the world, the supply of a commodity depends partly upon the total supply of the world and partly upon the facilities that exist for transferring it from other parts to that particular part of the world.

Thus, the supply of wheat in this country depends upon the facilities that exist for bringing it from America, Russia, and other countries.

Likewise the supply of labour in this country depends upon the facilities that exist for transferring it (or the products of it) from other countries to this country.

Any inequalities there may be in the value of either capital or labour in various parts of the world in consequence of local conditions of supply and demand, tend to produce a flow from those parts where the value is less to others where its value is greater, and thus to establish a condition of equilibrium.

The wonderful fleets of leviathan ships that to-day traverse every sea, and the giant railways that penetrate to the heart of every land, facilitate more and more, day by day, the flow of capital and labour, and thus increasingly tend to preserve equality in their respective values throughout the civilised world.

Now, let us call the value in exchange of a commodity, as determined by the law of supply and demand, its "market value." Then—

Capital has its market value ;
Labour has its market value ; and the
Product of the capital and labour has its market value.

And, clearly, if the market value of the product is not at least equal to that of the capital and labour, respectively, employed in its production, the production will decrease until its value reaches that point or will cease entirely. If the product is a *necessary*, the decreased supply will probably soon cause the value to rise to the point at which it is equal to the market value of the capital and labour employed. But the point is this : If either the capital or the labour employed in the production of any commodity or in any particular place can find more profitable employment in the production of any other commodity or in any other place, there is a natural tendency for either to flow to such other employments or places.

If an employer pays less than the market value for labour and reaps the benefit himself, the greater return for capital in that industry will attract the competition of other capitalists, while at the same time the

underpaid labour would be gradually diverted to more profitable employment, both of which causes tend to maintain capital and labour at their respective market values.

While, however, such are the *tendencies* to maintain equilibrium by the flow of capital and labour, the currents are not—to continue the metaphor—in a perfectly fluid but a viscous body—so that the flow is sometimes slow and equilibrium only partially preserved. Capital, for example, in the form of land, buildings or machinery, cannot always be readily adapted to another use. And a man who, after years of training, is skilled at one kind of work, cannot always readily adapt himself to another kind of work of equal value in exchange.

But, to continue our enquiry, let us see what results follow, or tend to follow, the "artificial" raising of the value of either capital or labour by means of combination among capitalists or labour respectively.

Labour combinations usually consist of persons engaged in the same class of work and within the same geographical area. The area may be a town or a district, a country or a group of countries. Variations in national characteristics and conditions, ideas, language, and other causes render co-operation over the larger areas less effective and, in fact, limit the scope of effective combination.

But whatever the extent of the combination, the object is to maintain, with relation to the rest of the world, a higher level of market value than that which they would possess if left to the free operation of the law of supply and demand.

The obstacles by which the flow that would naturally tend to equalise the value within and without the combination is resisted (and that are added by the combination to those that already exist) are, first, the exercise of persuasion (accompanied sometimes by force) to prevent the competition of their neighbours, and, secondly, with regard to other countries, the imposition of tariff duties upon the importation of such commodities as they themselves produce.

In this country, at present, the first only of these barriers is employed. Let us consider, then, the case of a combination of, say, the whole of the persons that are employed in this country in the production of any one commodity.

We have already seen that the supply of a commodity in a country depends not alone upon its production in that country, but also upon the facilities that exist for importing it from other countries. So that, in this case, if the commodity produced by the kind of labour in question is one that may be readily imported from other countries, the value of the labour in the combination will thereby and to that extent be kept in check.

In other words, we may say that as—

Supply depends (in part) upon facilities for import, and as
Market value depends upon supply (and demand), therefore
Market value depends (in part) upon facilities for import (and demand).

Now, if outside competition keeps down the market value of the commodity to such a level that when labour has been paid at its increased rate, there is less than the market value of the capital left, there will at once be a tendency for the capital to be diverted to more profitable uses. Thus, the employment in that industry in this country will decrease, and the foreign importation will increase.

A striking example illustrative of this came to light in August last, when a chainmaker was prosecuted under the Trade Boards Act for paying boys in his employ 12s. 6d. and 13s. per hundredweight for making a particular class of chain, whereas the minimum legal rate was 17s. From the evidence it appeared that the market value of the chain was only 17s. a hundredweight, which therefore left nothing—after paying the legal rate of wages—for material or other expenses or profit. The result of such legislation must clearly be to drive the trade and employment away altogether.

In this connection, I may relate what was said by the judge of the Federal Arbitration Court of Australia some two years ago while settling a dispute. He could not, he said, dictate to the employers what work they should carry on. But he could and would prescribe the conditions under which they must employ men, if they chose to employ them; and, if any industry could not afford to pay the "living wage" which the Court awarded, its remedy was to apply to the Federal Parliament for protective duties that would allow it to comply with the award.

Whatever may be said for or against the remedy suggested by the Australian judge, and whatever may be said as to the pros and cons of its application to our own country, at least it seems clear that by no other means can the free flow of competitive foreign labour be checked or prevented—the point that is germane to our present inquiry.

We see, then, that—

1. The extent to which the value of labour may be raised by combination depends upon the facilities with which it—or the products of it—may be imported; and
2. That any further increase tends to result in less home employment and more foreign importation.

But there is another result that may be noted. A rise in wages of one kind of labour is generally followed by a rise in other kinds of labour. Taking advantage of the "viscosity" of capital and the persuasive eloquence of the "picket" to stave off, at all events for a time, the effects of competition, one section after another succeeds in obtaining increased wages, which process tends to restore the original relative values in exchange. The wage earner, having in consequence to pay more for his commodities, may be really no better off in the last stage than in the first. And here, may I observe, that we are all of us, as consumers, thereby indirectly employers. When the miner buys his clothes or boots, he is indirectly employing the clothiers or bootmakers, and, in the same manner, when the clothier or bootmaker buy coal,

they are indirectly employing the miner. If all charge the same proportionate increase for their labour they will be neither better nor worse off for the change.

It is said that though in recent years rates of wages have been generally increased, the cost of living has increased in a still greater degree, which indicates that the demand for food-stuffs and other necessaries has increased more than the supply of the same. Neglecting fluctuations due to climatic causes, it would appear that this result is brought about by there being a smaller proportion of labour or capital—or of both—employed in the cultivation of food than hitherto.

Now with regard to combinations of capitalists, the principles that apply to labour apply also to capital. Such combinations exist for the purpose of maintaining, with relation to the rest of the world, a higher level of market value for their capital than that which it would possess if left to the free operation of the law of supply and demand. The extent to which their object can be achieved depends, like labour, upon the facility with which similar forms of capital, or the products thereof, can be imported. For that reason, in a country in such circumstances as this, having ample shipping communications with every part of the world, and no restrictions upon imports, the conditions for effective combination among capitalists are not favourable.

To sum up the answer that I have thus attempted to the question—What is it that regulates the proportion of the produce of the capital and labour employed which goes to the owners of the capital and to the labourers respectively? It s the law of supply and demand. Supply is dependent upon the facility with which the commodity may be imported, and upon the degree of this facility depends the extent to which the value of either capital or labour may be locally forced up by combination of capitalists or of labour respectively.

Now, we have seen that the production of commodities requires both capital and labour, and it is therefore safe to say that if the supply of either Capital or Labour falls below the amount which the other can profitably utilise, the supply of the product must be diminished. And, conversely, if both the factors of production are proportionately increased, the product will also be increased.

And it also appears that the greater the amount of produce to divide, the greater will be the amount received by the parties to the distribution.

Therefore I say—

Encourage Capital—it is necessary for employment.
Encourage Labour—it is necessary to render Capital productive.
Encourage the greatest possible *efficiency in production*—the "living wage" is measured by it.

NEWCASTLE LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

C. S. Vesey Brown, Member.

(Address delivered December 11, 1911.)

I thank you for the honour conferred in selecting me to act as your chairman for the ensuing session.

Amongst other matters to be considered are the proposed new Rules, and the session is likely to be productive of considerable discussion on account of the alterations suggested by the Council in order to strengthen the status and financial position of the Institution. It is to be hoped that any criticisms which may be made in connection with the suggestions put forward by the Council will be approached in that spirit which should animate every one who desires to see it strengthened, and the objects for which it was established safeguarded. I may here, perhaps, venture to hope that the addition of new members of all branches of the Institution to this particular Section during this next session may be larger in proportion than it has been in past years. Undoubtedly now is the time for electrical engineers to join and to give adherence to an Institution which has successfully carried on useful work for the last forty years.

Originally formed as a "Society of Telegraph Engineers and Electricians," the objects, as stated in its then Memorandum of Association were, amongst other things, "To promote the general advancement of electrical and telegraphic science and its applications, and to facilitate the exchange of information and ideas on these subjects amongst the members of the Institution and otherwise, and for this purpose to hold periodical meetings, to promote and hold inspections of instruments, apparatus, and to publish proceedings and reports, communications and treatises on any of the applications of electrical or telegraphic science." In 1883 it was felt by a number of members of this Society who were not particularly interested in the applications of telegraphy, but who were then working at the development of the applications of electrical science in other directions, namely, electric light, power and traction, that this title did not truly represent the status and profession of the majority of the members, and accordingly it was changed, and since then the original society has been known as "The Institution of Electrical Engineers."

From time to time the development of electrical science, as in other branches of engineering, has brought about outlets in which members of the Institution have specialised, and, with the spread of the knowledge in all the different branches of the industry which the Institution has been largely the means of disseminating, other Institutions and Societies have been founded, with the special object of advancing the knowledge of the particular subject under review. The same development has taken place in connection with the Institutions of Civil and Mechanical Engineers, and we all know that there are engineering societies devoting their energies to some special object in every manufacturing district in this country. One cannot forget, however, that all these engineering societies owe their original inception to the fact that the parent institutions were commenced, and have continued to remain, the fountain-head of each branch of the engineering profession, and though a local society, independent of any of these institutions, may be started and carried on so as to enable resident members of any particular branch of the engineering profession to meet and discuss technical questions in consequence of their inability to join in the principal discussions in London, yet, in the end, it is to the parent institutions that one appeals in all matters of principle and guidance by such an independent society.

It was in order to avoid the multiplication of these smaller societies in connection with electrical engineering, that some ten or eleven years ago the Institution of Electrical Engineers decided to form and foster "Local Sections" of the main Institution. These branches were chosen at the time to represent the different manufacturing districts where the greater majority of the members resided and carried on their business. It is impossible, of course, to have a Local Section in every town, and no doubt nearly as much inconvenience is occasioned to members who reside at some considerable distance from the local centre, as if that local centre had not been created and London remained the only place where discussions took place. I know of no district where this is so prominent as our own, and it is unfortunate that those belonging to this Section who are engaged in the electrical industry in the Tees district should be unable, on account of the distance, to attend the meetings in Newcastle. It is also a matter of regret that a more prominent part in our discussions is not taken by students. This may be due to a natural diffidence not to appear as a "semi-public orator," or it may not, but I can assure those students who feel at all nervous at the risk attached to "catching the Speaker's eye," that once done, there is no doubt that he will live to repeat the experiment. The discussions on papers are equally serviceable for asking questions or for giving information, and every one should take his part in making them useful. Propositions are being considered by your local committee to avoid these difficulties and to give improved opportunities to all members and grades of the Newcastle Section to take part in its proceedings.

It is now more than seventeen years since I first came to the North-

East coast as electrical engineer to the Sunderland Corporation. In 1894 the only electrical supply systems in operation were those commenced in 1891 by the Newcastle and District Electric Light and the Newcastle Electric Supply Company's at Forth Banks and Pandon Dene. Between 1894 and 1901 Sunderland and South Shields commenced operations, and in 1901 a considerable impetus was given to the supply of electric light, power, and traction, by the erection of a number of large and small power stations throughout the North-East coast.

I will not weary you with the details of the progress made, but it has been phenomenal. In the short space of ten years the kilowatt capacity of generating plant in public power stations has risen from 14,600 to 137,000, the output of units has increased from 4¼ millions to 225 millions, and the capital invested has grown from £660,000 to £5,000,000.

There is a word of praise and congratulation due to those who have assisted in bringing about this great transformation, especially when one considers that it has been done in the face of such cheap fuel as can be obtained locally for manufacturing purposes.

In 1902 I ventured to predict that during the next ten years a great development and investment of capital in electrical plant of all descriptions would take place on the North-East coast, and I even went so far as to suggest £10,000,000. When one adds the amounts spent by the various manufacturing interests represented in the railways, shipyards, engineering works, iron and steel works, collieries, and the hundreds of other trades carrying on business here, to the sums spent on public supply, I think that my prognostications will be proved to be nearly correct. I cannot hold out the same hope of a million a year for the next ten years, but just hope that it will be so and "wait and see."

The only possible large increase I can foresee at present is in the direction of railway electrification, and the attraction of those electro-chemical and metallurgical processes which require a cheap and reliable supply of power to maintain their position in the manufacturing markets of the world against foreign competition.

It is becoming more difficult each year for the chairman of this Local Section in following such distinguished predecessors, to choose some special object for his address which is congenial to his particular sphere in the electrical industry, and on which he is able to enlarge with facility in order to secure that rapt attention to the oracular statements which such addresses are generally alleged to require from a technical audience. More particularly so is this my case this evening, so to be on somewhat safe ground, and perhaps avoid too much criticism, I propose to place before you some points on the training requirements of an electrical engineer.

I do so all the more readily as I feel that too much attention cannot be drawn to the extraordinary and diversified character of the subjects upon which the electrical engineer is required to express an opinion, in callings quite alien to the application of electrical science.

It is not too much to say that he should have more than a little knowledge of law and accounts, and be ready equally well to discourse on how to find and repair a fault in a cable, give his views on the "then value" of electrical plant under the Electric Lighting Acts, or an estimate of the annual cost of energy used by an electric motor driving a brickyard as against suction gas with anthracite coal supplied at "next to nothing per ton."

The average man outside the electrical engineering profession has not the dimmest glimmer of an idea as to the educational training and requirements that most electrical engineers have to go through to be able to attain even a modest competence wherewithal to maintain himself, and I venture to say that in no other profession, except perhaps the medical, are the requirements of knowledge so rigid and varied.

The Charter of the Institution of Civil Engineers states, amongst other things that: "Certain subjects of his Majesty King George IV. have formed themselves into a society for the general advancement of mechanical science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a civil engineer, being the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states, both for external and internal trade as supplied in the construction of roads, bridges, aqueducts, canals, river navigation and docks, for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters, and lighthouses, and in the art of navigation by artificial power for the purpose of commerce and in the construction and adaptation of machinery, and in the drainage of cities and towns." After declaring that these loyal subjects have subscribed and collected considerable sums of money for these purposes, His Majesty goes on to grant to them and to those who shall hereafter become members of the said society, his Royal Charter of Incorporation, being desirous, as he expressed it, "of encouraging a design so laudable and salutary." I have quoted this extract from the Charter of the Institution of Civil Engineers because I cannot find that our own Memorandum of Association, even with this example before it, goes beyond the advancement of electrical and telegraphic science and its applications, without considering their direction for the "use and convenience of man," etc.

We may, however, I think rightly, hold that the general objects defined in the Charter of the Institution of Civil Engineers applies equally to this Institution, inasmuch as the majority, if not all of the members of this Institution, are devoting their lives and energies to the art of "directing one of the great sources of power in nature"—which we call electricity, and it is becoming more and more a necessity for the use and convenience of mankind as our knowledge of its applications develops.

The objective of the profession of an electrical engineer may therefore be taken to be on the lines indicated by the above quota-

tion, and it is in that direction that most of us have aimed to train ourselves.

The methods by which the training is carried out are various, and it is a subject which occupies the serious attention of every professor of all modern engineering schools and employers of labour in engineering workshops. Some years ago the following letter was written by the most eminent electrical engineer of our time in answer to an inquiry from a lady as to whether her son should be educated as an electrical engineer. The letter is dated 1884, and reads as follows :—

> "There is no business to make a profession of electrical engineering. There is, at present, very little work going on, and a great many people are learning. By the time the work comes it will be much easier for ordinary tradesmen and mechanics than plumber work and gas fitting is at present, and the whole amount of electrical work, though much greater than at present, may be done by a smaller number of leaders or scientific people with good salaries than at present. A young person intending to be an engineer or a mechanical engineer ought to learn electricity in addition to what it has been hitherto considered necessary to learn in engineering application, and so to be qualified to take electrical work in case of any opening, or, what is much more likely to be his case, to be ready to take charge or superintendence of any electrical work that may have to be done as part of any greater undertaking that he may be connected with."

This letter, as you will see, was written twenty-seven years ago, and during that period an enormous change has taken place in electrical engineering. At that time there were no Carvilles, Trafford Parks, Rugbys, Schenectady, A. E. G., etc. The workers and leaders in the applications of electrical science were few. They groped in the dark chasms of experimental data to find logical results to formulate a basis on which to build up practical results. In that sense the opinions expressed at the beginning of the letter were justified. And I think they are largely justified to-day taking into account the relative proportions of electrical work then done and what has been done since.

It is true that to-day we have a multitude of practical designers and scientific investigators, but what an enormously varied field of operations they have to work in! It is also my opinion that the advice given at the end of the letter applies equally to-day. The electrical engineer ought necessarily to occupy himself with nearly all questions involved in mechanical engineering in order to be able to follow the profession of an electrical engineer.

As a supplement to this opinion I will give you an American specification of the requirements of a good electrical engineer.

> "He must be of inflexible integrity, sober, truthful, accurate, resolute, discreet, of cool and sound judgment, must have

command of his temper, have courage to resist and repel attempts at intimidation, a firmness that is proof against solicitation, flattery, or improper bias of any kind, must be energetic, take an interest in his work, quick to decide, prompt to act, and fair and impartial as a judge on the bench ; have experience in dealing with men, and must have some business habits and knowledge of accounts. Men who combine these qualities are not to be picked up every day, still they can be found, but they are greatly in demand, and when found they are worth their price—rather they are beyond price—and their value cannot be estimated by dollars."

This strict specification of what a good engineer should be is a high standard to aim for, but I think you will all agree with me that there is no qualification mentioned in that specification which should not be strictly under penalty for non-fulfilment of the contract, and, as I will endeavour to show you later, the general requirements of an electrical engineer do not fall far short of the rigid terms imposed.

During the past year the Institution of Civil Engineers held the second General Conference on Education and Training of Engineers. The general education, scientific training, and the practical training were the three separate sections into which the Conference was divided. No definite conclusion was arrived at, but it was suggested that :—

1. The continuity of studies between public schools, where the elements of science are taught, and the universities and technical colleges should be improved.
2. That a closer connection between the science masters in the schools and the institution is desirable.
3. That the universities and technical schools should consider the desirability of a sandwich system of study, that is to say, six months at college and six months at a workshop.
4. That employers and technical colleges should co-operate more closely in order to give such practical training as might be obtained in twenty-four or thirty-six months on the sandwich system.

The members of this Institution will pardon my drawing attention to the proceedings of any other institution than their own, but my justification for doing so is that our own Institution has not yet taken into consideration any scheme, nor, as far as I know, have they recommended any form of training for an electrical engineer. That will, no doubt, come with the strengthening process now going on. To a large extent the electrical engineer has in the past been dependent for his training on the old principles which guided those responsible for the education of civil engineers, viz., school, drawing office, practice in the field, and then a "junior's job." The opinions expressed by those who took part in the Conference mentioned above were practically

focussed on the conclusions arrived at, with, of course, individual exceptions based on experience.

There can be no two opinions with those who consider that the first element of an engineer should be a sound general education with some knowledge of one or more modern languages, a good grounding in mathematics (including Euclid). It is a lamentable commentary on the rush of modern life that time cannot be found for the teaching of Euclid, which has been dropped in so many schools. The mental training induced by the logical sequence of problems which Euclid presents are the finest exercise for the balanced mind required in the solution of engineering problems.

At sixteen to eighteen years of age the student is taken from the steady discipline and regular instruction of a school to either a technical college or a workshop, and, as a rule, the choice is made irrespective of any particular idea other than to "teach the boy electrical engineering." It cannot be otherwise. No one can predict with certainty what will be the particular development of another human brain. One can only conjecture, help, and hope.

From that date onwards his career depends generally as to 90 per cent. on his own initiative and as to 10 per cent. on his surroundings. There are, of course, exceptions, when by chance an employer or a professor discovers the particular groove which is best suited to the student's brain, and forthwith gives every assistance to its development, but those exceptions are rare.

Having finished a two or three years' course at either of these establishments the student is considered to have imbibed sufficient information, and is then launched on to the world as a budding electrical engineer. In most cases it is necessary that he should immediately earn his living and be independent of those sources of supply hitherto available for his support. During the whole course of this training little or no attention can be given to what one may term the general knowledge and business requirements which it is found later on are necessary details to enable the rigid specification demanded by the competition of an overcrowded profession to be fulfilled.

It is my own opinion that the period allowed to the average student to educate himself up to the position at which the majority of electrical engineers should commence an active participation in the higher branches of electrical engineering has hitherto been too short, and I put in a plea for more breathing-space and a longer period in which to train in. I feel sure that it would be for the ultimate good of the electrical engineering profession if the period of training was increased to at least four years before any student was qualified and allowed to take many of the positions which are often filled by younger men. One hears on all sides that the profession is overcrowded, but the remedy is in the hands of those who are in it now. I believe that the mixture of theory and practice provided for in the sandwich system of education in Scotland would produce excellent results with benefit to the profession.

I might here give my views on the subject of examinations. As is well known, they are more often than not considered as the deciding factor in a student's ability compared with that of his fellows. An examination is, practically, made obligatory at all technical colleges, but little or no account can be taken in them of the student's ability to express his ideas in writing. I am quite sure that I am here expressing the views of a large number who have experienced the difficulties of transferring thoughts into words. As a matter affecting a decision on facts, and as an aid to memory, an examination is of value, but when it is necessary to reason out a problem it is sometimes difficult to appreciate the value of a written answer when stated in bald language. I will take, for example, the examinations which are conducted on behalf of a well-known Government Mining Department into the competency of electrical engineers in connection with coal-mines, and I give you a few questions culled from one of the latest set of examination papers. They will show you that the electrical engineer's knowledge is expected to be something beyond that of the application of electrical science, and this is where the general training to which I previously referred applies, and upon which I will further enlarge later.

1. Describe and illustrate with a diagram the windings and connections of a shunt-wound motor.

This is what one might term both a practical and theoretical question, and 20 marks are allowed by the examiner for correct answers. In contradistinction to this question 10 marks only are allowed for the following :—

2. In operating an electric coal-cutting machine in any gassy place, what are the duties of a machine-man as to inspection for gas, and what steps must be taken by him if gas is detected ?

This question involves a knowledge of conditions outside those appertaining to electrical engineering, and it will be noticed that the answer is relatively only 50 per cent. of value in obtaining the certificate of competency required.

Ten marks are allowed for the following question :—

3. What construction must be adopted for motors, starters, switches, etc., when such are worked in a gassy place? What precautions are to be taken in adjusting brushes of motors under these conditions?

As this involves very considerable experience of all types of manufacturers' standard makes, it is obviously a question which should be entitled to more consideration from the point of view of marks.

On the other hand, 20 marks appears to be too high for answering:—

4. What current will a 4-E.H.P. direct-current motor of 85 per cent. efficiency use with a terminal voltage of 250?

I quote these few examples, and I could give many more, not in any criticism of the questions put, because they lead, no doubt, in the judgment of those best qualified to give an opinion, to an effective control of the electrical engineers who are called upon to supervise installations of electrical appliances which may become dangerous to human life unless proper care is taken in their maintenance, but I do offer a protest against differentiating in the value of any particular answer as a means of identifying the electrical engineering student's ability. May I therefore put it to you that an examination for any particular purpose is not the final test as to a student's ability, but can only be taken as a guide to his knowledge of facts, and that he is the fortunate possessor of a retentive memory.

The electrical engineer has to face many difficult problems in the course of his career, which are not applications of electrical science. It is for that purpose that the period of training in college and workshop should include, if possible, such general subjects as will cover these contingencies.

Amongst other qualifications must be that of expressing himself in such terms in connection with electrical nomenclature that the ordinary lay mind can, as a rule, grasp the meaning. I have recently seen a list of definitions of electrical terms drawn up by an American association for the use of colliery officials and others who, having lacked the special training in electrical engineering, are sometimes called upon to take part in the handling or operation of electrical apparatus. The list is a long one, 74 terms in all, varying from "fuse" to "diversity factor." I have not the time here to give you either the list or the definitions, which, in some instances, are fairly intelligible, but for your information I pick out three, as showing what terms the electrical engineer is supposed to use, and side by side with it the meaning to the lay mind:—

"*Diversity Factor:* Diversity factor shall be used to express the relation between the simultaneous demand of all individual customers and the sum of the maximum demand made by these customers. The sum of the maximum demand of the customers, no matter at what time they occur, divided into the simultaneous greatest maximum demand, when expressed in per cent., will give the diversity factor."

This is a perfectly intelligible definition, and should be understood by the lay mind. A note is added to the explanation, which states: "It is a good thing not to have all the peak loads coming on the generating

plant at the same time." I think every one of my audience will appreciate the point of the note.

> "*Power Factor Indicator:* A device to indicate the power factor of an electric current."

This answer may possibly satisfy the majority of questioners, but I looked in vain for the term or definition of "power factor," and I think you will all agree with me that the very next question to be asked by a layman, after showing him a "power factor indicator," would be: "What is power factor?"

> "*Wattless Component Indicator:* A device for measuring the products of voltage of a circuit and the component of current at 90° with the voltage. This product is the heating effect in excess of the heating that would be given by a circuit of the same voltage and power at 100 per cent. power factor."

I leave it to my audience as to whether this definition would convey to the lay mind all that is covered by the term "Wattless Component Indicator."

I have given three examples out of a great number in order to further show how necessary it is that electrical nomenclature should be capable of a clear explanation easily understood by all, and also that the training of the electrical engineer is even more difficult to decide than is generally thought to be the case, and I ask those of you who have the inclination to work out the diversity factor in the exacting requirements of the profession based on his own experience over, say, one month. Who of us, for example, in commencing our careers, would expect that it should include, in addition to a knowledge of applications of electrical and mechanical science, a close acquaintanceship with the best conciliatory methods to pacify the irate customer who asserts that his meter reads incorrectly; or again, did it ever cross our minds that some knotty point would require solution in the Electric Lighting Act, the Public Health Act, the Coal Mines Regulation Acts (of which there are many), a contract, or what depreciation should be allowed on plant, any one of which matters may come up in the daily routine.

Another important factor in the electrical engineer's abilities from the point of view of his employer, especially if he be engaged on the commercial side of the business, is his ability either to buy or sell, depending in which direction his energies are employed. Nor can I forget to mention the ability to be able to deal with his fellow-man according to the circumstances of the case, whether he be a director, the chief engineer, a cross-examining lawyer, a client, a customer, a contractor, or, last but by no means least, the British working man.

I could quote further requirements of an electrical engineer's qualifications, but I think I have amply demonstrated that it is not the easiest of professions to graduate in, and that his education and training

are matters which cannot be decided off-hand, nor is it easy to define the routine to be followed. If I may say so, he is not "made," he is "induced" in the strong alternating fields of circumstances and surroundings. He is daily grappling with the problems connected with that great force in nature called "electricity," struggling to reduce it to a condition in which it will enable mankind either to earn his livelihood or dividends for the capitalist and, metaphorically speaking, produce two blades of grass where one grew before.

Of necessity he ought to be of a "hopeful" and cheerful disposition, not easily discouraged by the failure of a laboratory experiment or the non-fulfilment of a contract up to time. Moreover, he should—and my experience tells me that he does—maintain that spirit of determination to "do or die" in the combat with nature and mankind which makes the fight attractive to the properly balanced and scientifically trained mind. Finally, the electrical engineer with all his varied qualifications and requirements must never (please notice I personally use the word "must" for the first time in this address)—I say he must never forget that his real education only commences when he receives in current coin of the realm that sweet reward which is the fruit of his first week's work, and that his whole future career is but one long process of training and development.

Many of you have, perhaps, not considered how closely the two portions of my address are interwoven.

I have pointed out to you how extraordinarily varied are the experience and requirements of our calling and profession. It is because of these divergent interests and occupations all leading from one common standpoint, and the constant current of ideas flowing from one to another, the rapidity with which the wireless streams of thought alternate between those of you who are charged at such a high pressure with information that there is a risk of piercing the insulation of your minds; it is because all these things require some protective device to keep them in equilibrium that this section was established to maintain at its best the Institution of Electrical Engineers; and let us not forget that of all the mottoes which can be applied to its work none fit it better than "Union is strength."

•

A Special General Meeting of Members and Associate Members duly convened and held at the Institution on Thursday, November 2, 1911—Mr. S. Z. de Ferranti, President, in the chair.

The Secretary read the notice convening the meeting as follows :—

Notice is hereby given that an Extraordinary General Meeting of the above-named Institution will be held at the Offices of the Institution, Victoria Embankment, London, W.C., on Thursday, the 2nd day of November, 1911, at *half-past four o'clock* in the afternoon, for the purpose of considering, and if thought fit passing, as an Extraordinary Resolution the following resolution :—

RESOLUTION.

That the Articles of Association contained in the printed document submitted to the Meeting and for the purpose of identification subscribed by the Chairman thereof be and the same are hereby approved, and that such Articles of Association be and they are hereby adopted as the Articles of Association of the Institution, to come into operation as and from the 1st day of January, 1912, to the exclusion of and in substitution for all the existing Articles thereof.

By Order of the Council,
P. F. Rowell,
Secretary.

Victoria Embankment,
London, W.C.

25th *October*, 1911.

The President moved, and Mr. R. Hammond seconded, "That this meeting stand adjourned to a date to be notified, not being earlier than the 30th November, 1911."

After a short discussion the motion was put to the vote, and upon a show of hands was declared by the President to be carried.

The meeting was accordingly declared by the President to be adjourned as above.

Proceedings of the Five Hundred and Twenty-sixth Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, November 9, 1911—Mr. S. Z. de Ferranti, President, in the chair.

The minutes of the Annual General meeting, held on May 26, 1911, were taken as read, and confirmed.

Donations to the *Library* were announced as having been received since the last meeting from L. W. Austin, E. H. Barton, F. W. Beney, Professor H. Bohle, The British Insulated and Helsby Cables, Ltd., The Bureau of Standards, J. Burns, A. J. A. Butterfield, Professor H. S. Carhart, A. E. L. Chorlton, Dr. C. Chree, Messrs. Constable & Co., Ltd., Messrs. Crosby, Lockwood & Sons, G. R. Devey, K. Edgcumbe, The *Electrician* Printing and Publishing Company, Ltd., Dr. J. Erskine Murray, The Frederick Printing Company, P. W. Freudemacher, The Furukawa Mining Company, E. Garcke, Habibur R. Khan, Sir R. Hadfield, J. S. Haldane, H. R. Hamley, The Hill Publishing Company, Ltd., S. Hirzel, H. M. Hobart, W. H. Huskisson, The Hydro-Electric Company, Ontario, The Iron and Steel Institute, Dr. A. E. Kennelly, J. B. Lippincott & Co., G. C. Lloyd, The McGraw Publishing Company, Macmillan & Co., Ltd., The Metallic Compositions Company, The Meteorological Office, Mix and Genest A.-G., C. Mourlon, W. H. F. Murdoch, The Pacific Gas and Electric Company, A. Pacinotti, H.M. Patent Office, P. O. Pedersen, Physikalisch-Technische Reichsanstalt, Messrs. Purcell & Nobbs, S. Rentell, Professor D. Robertson, A. L. Rossiter, The Royal Society, Dr. A. Russell, The Smithsonian Institution, The Society of Engineers, E. and F. N. Spon, Ltd., The Standard Third Rail Company, W. T. Taylor, A. P. Trotter, The Victorian Institute of Electrical Engineers, F. Vieweg and Sohn, R. Wade, Sons & Co., Ltd., and T. F. Wall; to the *Museum* from The Electrical Standardising, Testing and Training Institution, The General Post Office, Mr. H. Hirst, Mr. H. F. D. Jacob, The National Telephone Company, Ltd.; to the *Building Fund* from the Associated Municipal Electrical Engineers (Greater London), J. Kynoch, W. McGeoch, Jun., J. E. Stewart, A. P. Trotter, and A. H. Unwin; and to the *Benevolent Fund* from The Electrical Engineers' Ball Committee, The Electrical Section of the Building Trades Gift to the Nation, The Reunion of Old Cromptonians,

A. M. Taylor, and J. H. Tonge, to whom the thanks of the meeting were duly accorded.

The President then presented the Premiums and Scholarships referred to in the Annual Report for the year 1910–11.

The following paper, "Modern High-voltage Power Transformers in Practice: with Special Reference to a 'T' Three-unit System," by William T. Taylor, Member (see page 55), was read and discussed, and the meeting adjourned at 9.55 p.m.

MODERN HIGH-VOLTAGE POWER TRANSFORMERS IN PRACTICE; WITH SPECIAL REFERENCE TO A "T" THREE-UNIT SYSTEM.

By WILLIAM T. TAYLOR, Member.

(*Paper received September* 11, 1911; *read before* THE INSTITUTION *November* 9, 1911, *and before the* BIRMINGHAM LOCAL SECTION *on November* 15, 1911.)

(In the absence of the author in South America the paper was read on his behalf by Mr. J. F. C. SNELL, Vice-President.)

To deal fully with a subject of this kind would cover a great amount of time and space, and as so much has been said in the past before this and other institutions of the theory of transformers—the properties of iron used in transformers—and other matters of equal importance connected with this apparatus, this paper will deal mainly with that part which particularly interests the operating engineer. This includes the practical operation, construction, types and systems to use, losses and costs.

Long-distance transmission of electrical energy has created a demand for a transformer which will operate satisfactorily on transmission lines extending over hundreds of miles. At first short distances only were applicable, but as the method of construction improved so that uninterrupted service could in most cases be relied upon, transformers were built for higher voltages, and now manufacturers are prepared to build them in units above 15,000 k.w. and at 200,000 volts. One large factory is using annually about 6,000 tons of steel and about 2,000 tons of copper in the manufacture of transformers. In that factory there are facilities for testing over 150,000-k.w. capacity of power and lighting transformers of sizes above 100 k.w. in each month. There are about 30,000 tons of transformers shipped annually from this factory. The history of transformer manufacture reveals that the first transformers used by Faraday in his historic experiments had for their magnetic circuit a closed ring of iron. Varley in the year 1856 pointed out the disadvantage of leaving the magnetic circuit open, and gave it a closed path by bending back and overlapping the end of the straight iron-wire core. In the early days of electric lighting Ferranti modified Varley's method by using, instead of iron wires, strips of sheet iron bent back and interlaced. The then nearest approach to present-day practice was to embed link-

shaped coils in the recesses of a core built up of shaped stampings, afterwards completing the magnetic circuit either with sheets of laminated iron or with strips interlaced with the ends of the projecting legs. From this construction the "shell"-type transformer probably received its name.

In selecting a transformer the following important factors must be carefully considered :—

(*a*) The ratio of iron and copper losses should be such that the total resultant losses are a minimum.
(*b*) The capital cost of the transformer and the cost of its total annual losses should be a minimum.
(*c*) Reliability.

The real cost of a transformer depends upon the amount which must be paid for the losses incurred during the life of the transformer and upon the first cost of the transformer. In considering these losses and the price paid for a transformer together, the losses may be conveniently represented as capital by multiplying their annual cost by the life represented by interest and depreciation.

Safety to life, durability, and economy are essential features of a transformer, but the factor that really determines the value of this apparatus is its ability to give continuous and uninterrupted service. These features are sometimes sacrificed to obtain a higher efficiency, especially in high-voltage transformers where so much insulation has to be used. This is not good practice, and a transformer designed and built with the main object of efficiency at the expense of safety and reliability finally brings discredit to its makers. The loss in revenue alone due to the failure of a large power transformer would more than counterbalance the saving of several years due to an additional 1 per cent. in efficiency, without counting the great loss of confidence of the customers. The application of knowledge gained by many years of constant and careful study of all of the properties and characteristics of transformers in actual practice has placed this type of apparatus on a plane which is now both safe and reliable for operating voltages as high as 110,000 volts. Looking back over the development of the transformer the time is not distant when large units of moderately high voltage (20,000 volts) were considered by manufacturers a difficult if not altogether a dangerous proposition—in fact, quite as dangerous as designing and building to-day a transformer to give an output of 20,000 k.w. at 200,000 volts. Commercial transformers have already been built for and are operating at voltages as high as 500,000 volts in small units of 200 k.w. The author believes there will shortly be transformers in operation in testing departments at much higher voltages than even this, and also that power transformers will be built in units of 20,000 k.w. at 200,000 volts.

Whenever water is available and not expensive, water-cooled transformers are preferable to air-blast transformers of large and moderate sizes (2,000 to 10,000 k.w.), as it enables operation of trans-

formers at lower temperatures and thus allows more margin for overloads. Where water is not available, there is a choice of two kinds of air-cooled transformers—either the oil-filled self-cooled type, or the air-blast type which is cooled by a forced air circulation through the core and coils. This latter type is not very reliable for voltages above 33,000 volts, principally on account of the great thickness of the solid insulation needed and the consequent difficulty in radiating heat from the copper.

A great deal has been said about the fire risks of air-blast and oil-filled transformers, but this is a matter that depends as much on surrounding conditions and the location of the transformers as on their construction. The air-blast transformer contains a small amount of inflammable material compared with the oil-filled transformer, but this material is much more readily ignited. A breakdown in an air-blast transformer is usually followed by an electric arc which sets fire to the insulating material, and the flame soon spreads under the action of the forced circulation of air. Although the fire is of comparatively short duration, it is quite capable of igniting the building unless everything near the transformer is of fireproof construction. The chances of an oil-filled transformer catching fire on account of any short circuit in the windings are extremely small, because oil will burn only in the presence of oxygen, and, as the transformer is completely submerged in oil, no air can get to it. Moreover, the oil used in transformers is not easily ignited; it will not burn in open air unless its temperature is first raised to about 400° F. And also, with oil at ordinary temperatures, a mass of burning material can be extinguished as readily by immersing it in the oil as in water. The chief danger of fire is not that the oil may be ignited by any defect or arc within the transformer, but that a fire in the building may so heat the oil as to cause it to take fire. The idea of placing oil-filled transformers in separate compartments is not thought so necessary now as it was some years ago.

A large variety of transformers is now made, but the two designs best known are the "shell" and the "core" types. The operating engineer is interested *qua* design, mainly in the following particulars:—

(*a*) Type of transformer.
(*b*) Number and arrangement of magnetic circuits.
(*c*) Form and arrangement of primary and secondary coils.
(*d*) Process of impregnation and drying of coils.
(*e*) Insulation and insulating material.
(*f*) Oil ducts between coils and core.
(*g*) Form and kind of tank.
(*h*) Core and copper losses.
(*i*) Temperature.
(*j*) Regulation.
(*k*) Cost.
(*l*) Efficiency.

Of these factors only four affect the operating costs, namely, the core and copper losses, the temperature, the regulation, and efficiency. All of these factors represent quite a large sum during the life of a transformer. The hysteresis and eddy-current losses are generally combined under the term of "core loss." The hysteresis in a given steel varies with the composition, hardness, frequency of reversal of magnetism, maximum induction at which the steel is worked, and with the temperature. The hysteresis loss varies approximately as the 1·6th power of the induction, and inversely as the frequency.

The eddy-current loss varies inversely as the ohmic resistance, directly as the square of the induction, and decreases as the temperature increases. It is greater in thick than in thin laminations—hysteresis being greater in hard steels than in soft steels—the eddy-current loss is also greater as the insulation between adjacent laminations is less.

Lowering the frequency of supply will result in increased hysteresis and higher temperature in the iron; reducing the frequency from 133 to 125 cycles, for instance, will entail an increased hysteresis of about 4 per cent., and a reduction from 60 to 50 cycles will raise the hysteresis approximately 10 per cent. A reduction of 20 per cent. in the frequency will increase the transformer exciting current about 14 per cent.

For the same output there will be no change in the copper loss, but in the case of large power transformers the increased temperatures due to excessive iron losses will materially decrease the output, and the normal rated secondary current or low-voltage current will become a virtual overload.

It is interesting further to note that an increase of about 10 per cent. above normal frequency at the rated voltage will lower the iron loss by nearly 20 per cent., while the exciting current will be considerably increased. Due to this smaller iron loss the secondary current may be larger for the same temperature rise, thus affording a greater available transformer output and an increased all-day station efficiency.

The cost of this core loss may be approximately expressed as :—

$$\text{Iron loss cost} = \frac{W}{1{,}000}(K + k),$$

where W represents the iron loss in watts; K the cost of energy per kilowatt-hour in pence; k the annual charge in pence per kilowatt capacity of station and transmission lines.

Iron loss and exciting current, in addition to decreased kilowatt capacity, result in greater coal consumption, both these factors being directly opposed to economical operation, and as the iron loss is practically constant while the transformers are connected to the system, no matter what the load may be, the total yearly loss will represent a great loss in revenue.

While the core or iron loss is practically constant at all loads, the

copper or I^2R loss varies as the square of the current in both the high- and low-voltage windings.

The latter is within easy control of the designer, as a greater or less cross-section of copper may be provided for the desired regulation. In a transformer core of a given volume and area, the number of turns for the required iron loss is fixed. To secure the desired minimum copper loss, advantage is taken of a form of coil wherein the mean length per turn is kept as low as possible with the necessary cross-section of copper. If the form of coil be rectangular it is evident that the mean length per turn of the conductor would be increased, provided the same cross-section of area of the core were enclosed, so in order to secure the shortest mean length per turn consistent with good construction it is necessary to adopt a square core in which the corners have been cut off. Also, in order that the greatest amount of conductor may be accommodated in the available space, all wire entering into the low- and high-voltage windings is either square or rectangular in shape. By using this form of conductor the area is increased by about 33 per cent. over that of ordinary round wire. This method permits the copper loss to be reduced, and at the same time allows a greater part of the total copper loss to take place in the high-voltage winding. The drop in voltage due to eddy currents in the conductors, and due to magnetic leakage, is minimised by the use of several small conductors of an equivalent cross-section. The loss due to magnetic leakage is made negligible by virtue of compact construction and the proper disposition of the windings with relation to each other and to the core.

The cost of this copper loss may be approximately expressed as :—

$$\text{Copper loss cost} = \frac{W}{1{,}000}(K + p\,k),$$

where W represents the copper loss in watts ; K the cost of energy per kilowatt-hour in pence ; p the ratio of the peak station kilowatt capacity to the connected transformer kilowatt capacity ; and k the charge in pence per kilowatt capacity of station and transmission lines.

The copper loss generally represents a less cost than the iron loss, due to the reduction in output charges arising from the short duration of maximum load. It also has a slightly less capital cost due to the diversity factor.

The losses due to the magnetising current and heating are determined from the manufacturer's guarantees. The exciting current of a transformer is made up of two components, one being the energy component in phase with the E.M.F., which represents the power necessary to supply the iron loss, the other component being in quadrature with the E.M.F., generally known as the magnetising current, and which is wattless with the exception of a small I^2R loss. The magnetising current shows very little influence on the value of the total current in the transformer when it is operating at full load ; but as the load

decreases, the effect of magnetising current becomes more prominent until at no load it is most noticeable. The greater the exciting current the greater is the total current at the peak of the load, and hence the greater must be the generating station equipment and transmission lines to take care of the peak.

The total cost of magnetising current may be approximately expressed thus:—

$$\mathit{Line} = m\left(Cf + \frac{M}{2}\right)\frac{P\,K \times x}{1{,}000} \text{ in pence,}$$

and—

$$\mathit{Station} = m\left(C_1 f + \frac{M}{2}\right)\frac{P_1\,K_1 \times X}{1{,}000} \text{ in pence,}$$

where m is the magnetising component of exciting current in volt-amperes; C, C_1 the average wattless component of the line load and average all-day wattless component of total station load respectively; f the fundamental frequency; M the magnetising component of transformer exciting current, expressed in terms of the line current; P, P_1 the line loss expressed in terms of line kilovolt-amperes, and generator losses in terms of full load kilovolt-amperes respectively; K, K_1 is cost of energy per kilowatt-hour in pence; x is the cost of line per kilovolt-ampere, and X the cost of generators per kilovolt-ampere.

The actual cost of magnetising current is in some cases of considerable importance and should not be neglected, particularly where the installations are large.

It is often said that regulation reduces the voltage upon the load, and therefore causes a direct loss of revenue by reducing the power sold. If, however, the mean voltage with transformer regulation is maintained at the same value as the constant voltage without regulation, the power delivered to the customer will be the same in both cases, hence there will be no direct loss of revenue. As the regulation of transformers is effected at high power factor mainly by resistance, and at low power factors mainly by reactance, both should be kept as low as possible. With non-inductive loads the regulation is nearly equal to the ohmic drop, the inductance having but little effect. With an inductive load the inductance comes into effect, and the effect of resistance is lessened and is dependent on the power factor of the load. In general, the core-type transformer has not so good a regulation as the shell type. The reason of this is, that in the shell-type transformer there is a better opportunity for interlacing the coils. A well-designed transformer should not only maintain a low average temperature, but the temperature should be uniform throughout all its parts. The only efficient way of insuring uniform temperature is to provide liberal oil ducts between the various parts of the transformer, and these must be so arranged in relation to the high- and low-voltage coils as to give the best results without sacrificing other important characteristics. Such ducts necessarily use much available space and make a high-voltage transformer of given efficiency more expensive than if the space could

be completely filled with copper and iron. In view, however, of the reliability and low deterioration of a transformer of this construction, experience has demonstrated that the expense is warranted.

The efficiency of a transformer is the ratio of the output to the input, and if the losses are known for the different loads the efficiency is easily determined. Where a transformer is operated at full load its "all-day" efficiency will be almost equal to its full load efficiency. Where a transformer is not operated at full load throughout the day, its "all-day" efficiency will decrease as the load decreases. The "all-

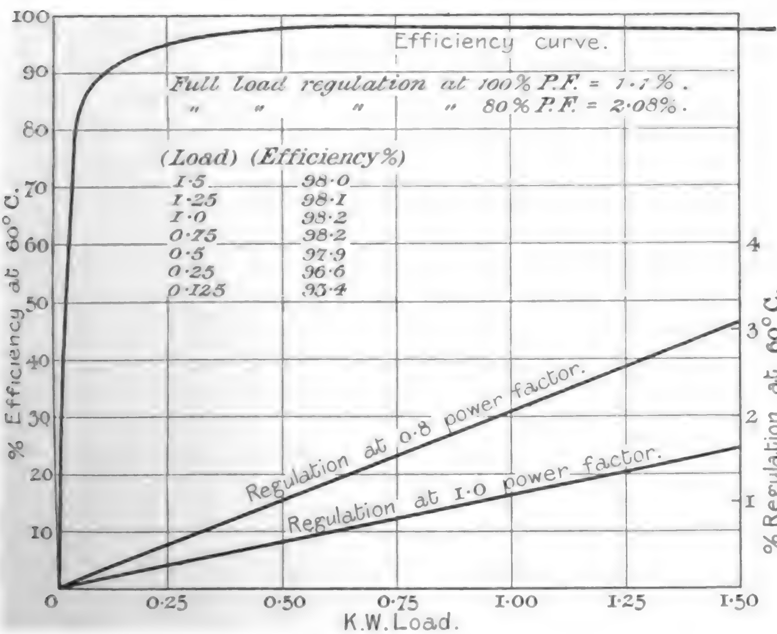


FIG. 1.—Transformer: Efficiency and Regulation—Shell-type 25-cycle 22,500-volt Oil-filled Water-cooled.

day" efficiency is an important matter to operating engineers, and in general it is found that transformers will operate economically and quite satisfactorily when worked at their limiting temperature rise. This may mean an overload for short periods of time, hence a high ratio of copper and iron loss and of course decreased first cost of transformers. The increase in first cost of transformers which are too large is greater than the capitalised cost of the reduced losses, and a careful study of conditions governing the loads should be made before a final decision is taken of the exact size to adopt for a given service. In making a choice of transformers it is sometimes difficult to decide exactly upon one particular type that will best suit conditions of load, character of

load, and locality. It is unwise to follow strictly a rule of choosing equal kilowatt capacity for equal generator units, although in some particular cases this will hold.

In Fig. 1 the efficiency and regulation of shell-type transformers are shown. It will be noted on looking carefully over the diagram that the efficiency is rated high and well maintained over a wide range of load. The regulation also indicates special care in design to reduce magnetic leakage and to make the resistance drop a minimum.

TABLE I.

Single-phase Oil-filled Water-cooled 25-cycle 66,000 to 6,600-volt Transformers.

Output in Kilowatts, 40° C. Temperature Rise.	Load Efficiencies.				Gallons of Oil.	Gallons of Water per Minute.
	100 per Cent.	75 per Cent.	50 per Cent.	25 per Cent.		
100	95·3	95·0	94·1	90·2	200	2·0
125	95·7	95·5	94·5	90·8	200	2·5
150	96·0	95·7	94·8	91·2	250	2·5
200	96·4	96·2	95·3	92·0	250	3·0
250	96·7	96·4	95·5	92·4	350	3·5
300	96·9	96·7	95·9	92·9	350	3·5
333	96·9	97·0	96·5	94·7	550	3·0
375	97·0	97·1	96·5	94·9	650	3·5
400	97·1	97·2	96·0	95·0	700	3·5
500	97·3	97·4	96·9	95·4	750	5·0
667	97·5	97·5	97·1	95·7	750	6·0
750	97·6	97·6	97·2	95·9	750	6·5
875	97·7	97·7	97·3	96·0	1,400	7·5
1,000	97·8	97·8	97·4	96·2	1,400	8·0
1,250	98·0	98·0	97·7	96·6	1,550	9·0
1,500	98·1	98·1	97·8	96·7	1,600	11·0
2,000	98·3	98·3	98·0	97·1	1,800	13·5
2,500	98·4	98·4	98·1	97·2	1,800	16·0
3,000	98·5	98·5	98·3	97·4	1,950	18·5
3,500	98·6	98·6	98·4	97·6	2,150	20·0
4,000	98·7	98·7	98·5	97·7	2,300	21·0

Not very long ago a transformer was designed known as the "forced-oil type," the first designs having their oil-cooling outfit exterior to the transformer. Modern designs of this type have their cooling coils located within the transformer tank, being separated from the main body of oil by a sheet-steel diaphragm. The heated oil is pumped from the top of the transformer and discharged into the upper part of the cooling compartment, and by continuous operation of the pump the cooled oil flows out from the bottom of the compartment and up through the spaces or ducts between the windings and the core. The

forced-oil cooling-type transformers are used in sizes above 2,500 k.w. for single-phase and 7,500 k.w. for 3-phase.

In Tables I. and II. there is shown a class of single-phase oil-filled water-cooled transformers 25 and 60 cycles respectively, giving the efficiencies at various loads; the sizes of transformers varying from 100 to 4,000 k.w.

TABLE II.

Single-phase Oil-filled Water-cooled 60-cycle 66,000 to 6,600-volt Transformers.

Output in Kilowatts, 40° C. Temperature Rise.	Load Efficiencies.				Gallons of Oil.	Gallons of Water per Minute.
	100 per Cent.	75 per Cent.	50 per Cent.	25 per Cent.		
100	95·6	95·4	94·4	90·8	100	2·0
125	96·0	95·7	94·7	91·2	150	2·0
150	96·2	95·9	95·0	91·5	200	2·5
200	96·6	96·3	95·3	92·0	200	3·0
250	96·9	96·7	95·9	93·1	250	3·0
300	97·2	97·0	96·3	93·8	250	3·5
333	96·8	97·5	95·6	92·4	550	3·5
375	97·0	96·7	95·9	92·8	600	3·5
400	97·1	96·8	96·0	93·0	600	5·0
500	97·3	97·0	96·3	93·5	600	5·0
667	97·6	97·4	96·7	94·2	650	5·5
750	97·7	97·5	96·8	94·5	650	6·5
875	97·9	97·7	97·1	95·0	650	7·0
1,000	98·0	97·8	97·2	95·2	650	7·5
1,250	98·2	98·0	97·5	95·6	800	8·0
1,500	98·3	98·1	97·6	95·9	1,500	9·5
2,000	98·4	98·2	97·8	96·1	1,600	12·5
2,500	98·5	98·4	97·9	96·3	1,600	15·0
3,000	98·6	98·5	98·1	96·6	1,700	17·5
3,500	98·7	98·6	98·2	96·8	1,800	18·5
4,000	98·8	98·7	98·3	97·0	1,950	19·5

It is interesting to note how the values given in Table I. compare with those shown in Table II. The regulation for the class of transformers shown in the first table for non-inductive load varies from 2·5 per cent. to 1·6 per cent. in sizes up to 300 k.w., and from 2·4 per cent. to 1·2 per cent. in sizes from 350 to 4,000 k.w.; while the regulation of the 60-cycle list varies under non-inductive load from 2·3 per cent. to 1·4 per cent. in sizes up to 300 k.w., and from 1·75 per cent. to 0·90 per cent. in sizes 350 to 4,000 k.w.

A general idea of the comparative efficiencies and floor space, etc., of oil-filled water-cooled and air-blast transformers can be gained from Table III.

Construction of High-voltage Transformers.—It is quite well understood that there are various types of transformers on the market to which manufacturers have given the name of "core-type" and "shell-type" transformers, although some of them differ so much in design that it is quite a difficult matter to the operating engineer to tell just how to classify them. However, the designs of transformers referred to herein strictly cover the core and the shell types, and are of the large output high-voltage kinds.

Transformers are always sent from the factory as completely assembled in their tanks as their size and the transportation facilities in the countries they have to pass through will warrant. When they are sent disassembled, which is usually the case if they are for very high voltages, the tanks are all protected for shipment abroad but left unprotected for home shipment; the coils are carefully packed in weather-proof boxing. The core of the shell type is packed in strong wooden boxes of moderate size (in a loose condition). That of the core type is shipped already assembled, each leg being packed in one box and the end-laminations in separate boxes. Whether the transformer is built up at its destination or sent already assembled, it should be thoroughly inspected before being permanently put into the tank. If the transformer is sent from the factory in its tank, which is very seldom done, it should be removed and thoroughly inspected and cleaned before giving it a "heat-run."

Dealing first with the "core-type" transformer, which consists essentially of two or three cores and yokes which together form a complete magnetic circuit, these cores and yokes are made up of laminated stampings, which vary according to different manufacturers from 0·010 to 0·025 in. in thickness, the laminations being insulated from each other by a coat of varnish or paper to limit the flow of eddy currents.

Fig. 2 shows that there are three cores of equal cross-section joined by top and bottom yokes of the same cross-section as the cores, and that upon each core are placed the low- and high-voltage windings for one phase. The low- and high-voltage windings are connected so that the fluxes in the cores are 120 electrical degrees apart, making their vector sum equal to zero at any instant.

The usual designs of core-type transformers made by the manufacturers have a uniform distribution of dielectric flux between high- and low-voltage windings, except at the ends of the long cylinders, where the dielectric flux will be greater and its distribution irregular.

As already stated, the core-type transformer has its laminations shipped already assembled, wrapped in insulating material of horn-fibre and bound with strong binding tape, which serves as a binding to keep the laminations of the assembled sections intact. The different sections are assembled on wooden pins of the size of the holes in the laminations: first, with the end having longer dimensions between its end and pin-hole in one direction, and then this end in the opposite direction, alternating spaces thus being left for assembling the end

33,000 to 6,600-volt Transformers.

ons of ater Minute.	Floor Space.	Height to Top Cover.
	Inches.	Inches.
1·5	45 × 31	84
—	**38 × 33**	**86**
2·0	45 × 31	84
—	**38 × 33**	**87**
2·0	48 × 32	88
—	**47 × 38**	**88**
2·5	54 × 36	93
—	**47 × 38**	**89**
2·5	54 × 36	93
—	**50 × 41**	**91**
3·0	62 × 40	102
—	**50 × 46**	**92**
3·0	68 × 38	120
—	**50 × 46**	**94**
3·5	68 × 38	122
—	**50 × 46**	**95**
4·5	68 × 38	123
—	**51 × 49**	**98**
6·0	68 × 38	130
—	**56 × 49**	**103**
7·0	78 × 42	130
—	**57 × 49**	**108**
8·0	84 × 50	140
—	**64 × 56**	**112**
9·0	84 × 50	150
—	**64 × 56**	**115**
1·5	84 × 50	157
—	**64 × 56**	**121**
4·0	94 × 59	155
—	**72 × 62**	**126**
6·0	94 × 59	160
—	**80 × 68**	**130**
8·5	107 × 63	150
—	**84 × 78**	**134**
9·5	107 × 63	150
—	**90 × 74**	**137**

ooled transformers.

laminations. The approximate number of laminations per inch required in building up these laminated sections may be determined from the information that the iron, solid, would be about 90 per cent. of the height of the built-up laminations, 36 and 64 laminations per inch being about the number of laminations required for the two-standard thicknesses, 0·025 and 0·10 in. respectively. The required number of laminations is built in an insulating channel-piece, and on the top of this channel-piece and the pile of laminations another channel-piece is placed, the whole being pressed down to dimensions and the channel-pieces stuck together with shellac under the influence of pressure and heat. The various sections are then assembled with wooden pins to

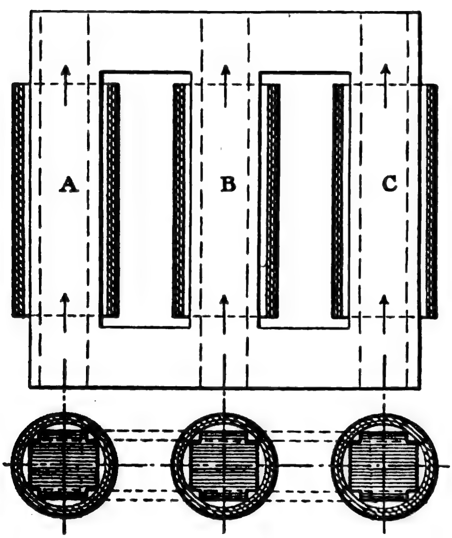


FIG. 2.—Three-phase Core-type Transformer.

hold them together, these remaining in the holes permanently, and the assembled sections clamped to dimensions and wound with a layer of strong binding tape (half-lap), which must not extend beyond the beginning of the spaces for the end laminations.

Now that the core is built up, the bottom end laminations should be inserted, their number corresponding to the spaces left for them, making them so fit into the spaces as to form butt-joints. These end laminations are assembled while the cores or "legs" are resting in an horizontal position. While in this position the bottom clamp with its insulation is fastened over the end laminations and the whole raised by the help of another clamp and cross-bars to a vertical position, with open ends up. The clamping bolts are then placed in loosely, relying on the bolts which hold the bottom clamps in position to keep

the cores in a vertical position during the assembly of coil supports and coils.

The coils, which are of a cylindrical form, are raised by means of a stout tape and slipped over the cores. All of the coils which connect

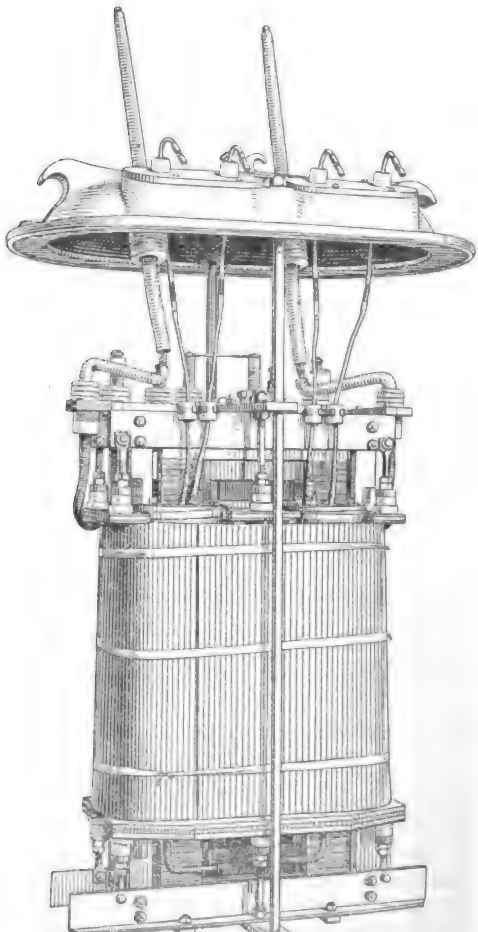


FIG. 3.—60,000-volt Single-phase Core-type Transformer.

together at the bottom should be connected immediately after the coils are in position. Between the low-voltage coils and the high-voltage coils a cylinder-shaped insulating separator is placed, the separator being held in position by means of spacing strips of wood. All

connections between outside coils can be conveniently made before the spacing strips are inserted between the high- and low-voltage windings, when the coils may be easily turned to such positions as will leave the coil connections as distant as possible from the side of the steel tank. The top connections should be made after all the coils of the high-voltage winding are in position. A pressboard insulating-piece or casing is finally placed over the whole assembly of coils and tied around with tape (see Fig. 3).

The connections leads are brought out at the top and supported in a similar manner to those mentioned in the assembly of shell-type transformers.

The "shell-type" water-cooled transformers and forced oil-cooled transformers are built in larger sizes than the core-type transformers, the former type having been built in 6,000-k.w. single-phase units and 10,000-k.w. 3-phase units.

The shell-type transformer shown in Fig. 4 consists of three single-phase transformers placed in one tank, the laminated cores being

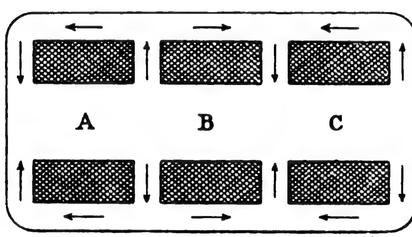


FIG. 4.—Three-phase Shell-type Transformer.

constructed so as to form a single structure. The reduction of steel for the magnetic circuit amounts to from 10 to 20 per cent. of that used in three single-phase transformers placed side by side.

In this type of transformer it is difficult to insulate the large number of edges and sharp corners exposed between adjacent high- and low-voltage windings and between windings and core. At these places the dielectric density is very great, and it is a much more difficult matter to insulate them than the ends of the cylinder coils of a core-type transformer. Much more insulation is required and consequently a smaller space factor. In fact, a 60,000-volt. 2,000-k.w. 25-cycle transformer of the core type will have a space factor of the windings (ratio between the total section of copper in the conductors to the total available winding space), of about 28 per cent., whereas in the shell type of the kind shown in Fig. 4 the space factor is only about 17 per cent. The result of this diminished space factor in the windings of a shell-type transformer is lower efficiency and worse regulation, and consequently a heavier and more expensive transformer for a given output and efficiency. It is sometimes recommended that graded

insulation should be used in high-voltage transformers between the high-voltage and low-voltage windings or between the windings and core because of the unequal distribution of the dielectric flux. In all properly designed transformers for high voltages the only change in the insulation is at the ends of the windings.

In assembling the coils of a shell-type transformer, care should be taken to eliminate dirt and dust, and the coils at all times must be kept clean and dry. In unboxing the coils, each one should be wiped off with a dry cloth and stacked in the right order for assembly. The assembly for coils is begun on an horizontal plane, the outer press-board insulation-piece being set on two wooden horses correctly spaced, depending on the size of the transformer. The first coil, taken

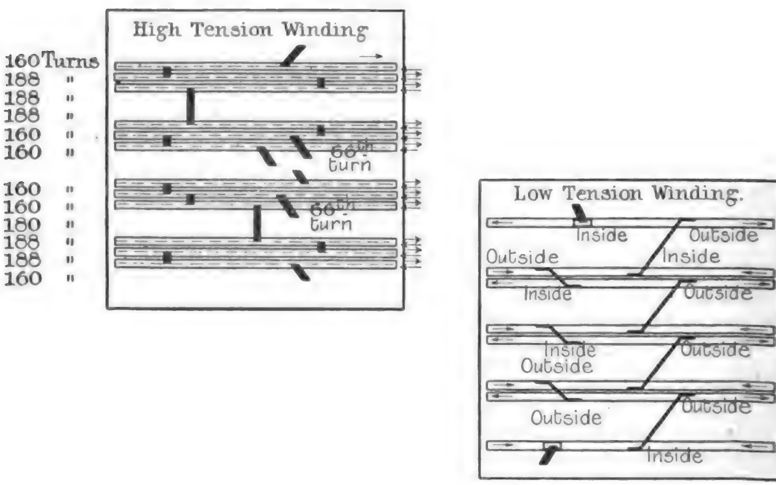


FIG. 5.—End View, showing the Arrangement of Coils of a Shell-type Transformer.

from the top of the stack, is placed in position with its inner edges insulated by means of channel-shaped insulation-pieces. Each coil before it is so placed has the same shaped insulation-pieces placed on its outer edges; insulation separators are arranged in a symmetrical order for both the low- and high-voltage coils with wooden filling blocks and channel-pieces set at the inside top and bottom of the coils. The assembly of these coils is usually done in accordance with erection drawings, like that shown in Fig. 5.

In connecting the coils together, all soldering is best done as the assembly progresses, also all taping of the connections, since the short stub connections are only accessible at this stage of erection. Before beginning to solder, a cloth should be spread over the ends of the coils to prevent solder being splashed on them which might get inside the coils and ultimately cause a burn-out. During the assembly of

coils, great care should be taken to keep them and the insulation separators in alignment. To facilitate this, all the insulation separators are slotted at their four corners and a long strip of wood is threaded through as the coils are built up. After the assembly of coils has been completed and the outside top insulating-piece or collar placed in position, the whole is clamped down to dimensions. While the end clamps are holding down the coils, strong cloth tape is wound around the coils, between the two clamps, under considerable tension, the end of tape being finally secured by sewing it down, after which it is painted with a black insulating air-drying varnish.

Getting the assembled coils from the horizontal position in which they rest to a vertical position necessary for the assembly of the core and completion of transformer requires the greatest care, especially

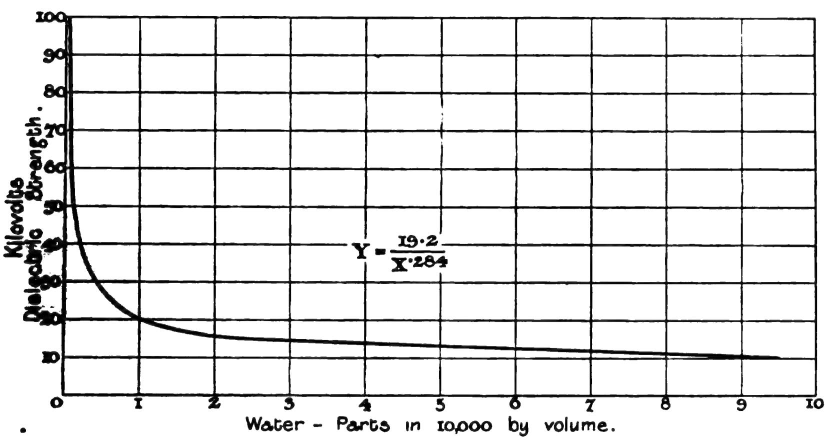


FIG. 6.—Effect of Water on the Dielectric Strength of Oil.

where transformers are of a larger size than 2,000 k.w. This is accomplished by means of blocking the space, inside of the coils, and leaving sufficient space in the centre of the coil-space for a lifting-piece. The rope or cable for lifting should be slid over the rounded ends of the lifting-piece, care being taken that the wooden spacer is sufficiently high.

The bottom end frame, or core support, is now ready to be set into position where it is desired to build up the iron, which is arranged in a similar manner to that shown in Fig. 6. The coils should be lowered easily into position, so the parts of the wood frame between core and casting, which rest on the coils, should extend slightly above the parts of the wood frame which rest on the casting, thus allowing space for the coils to settle down.

The iron laminations of shell-type transformers must be laid with great care, steel pins being used to keep the alignment, on which the laminations butt vertically. Lapping of the laminations must be avoided, otherwise difficulty will be experienced in getting in all of

them. Raw-hide mallets should be used for driving the laminations into line; or, in case these mallets are not available, hard wood-pieces pressed against the laminations may be hammered. During the building up of the laminations they should be pressed down two or three times, depending on the size of the transformer. For this clamping, the top iron frame is usually lowered and forced down with special clamps, or the regular clamping bolts may be used if the threading on these bolts is sufficient to lower the clamp to the required dimensions; these clamps or bolts may be left in position over night if any difficulty is found in getting in the laminations. In the case of transformers without a top-piece or frame, a specially constructed rigid frame of wood may be used. The laminations should be built up to such a height as will permit the core-plate to be forced into position under considerable driving. It is always a difficult matter to put in all the laminations that come from the factory, as special facilities for pressing are available there. After the laminations have been clamped down, the low- and high-voltage leads should be supported and insulated, care being taken when supporting the leads to see that they are properly spaced, as if they are placed too close together a short-circuit might occur. At the cast-iron frames, insulator bushings are used for this purpose which are held by metal supports to the frame, and at the point where the leads pass through the bushings cement is used to hold the leads in position. Both the high- and low-voltage end-leads connect to the terminal-board, which is located above the assembled coils and core. In the case of oil-cooled and water-cooled transformers all the leads are brought out at the top; usually the leads from air-blast transformers terminate at the base, or partly at the base and partly at the top of assembled coils.

In lowering transformers into their tanks, care must be taken to find the bottom cross-bar, into which the core tie-bolts are screwed, so that the transformers shall be properly centred in the tank.

Of the two types, the core type is the easier one to assemble, and a full description of one particular method of assembly of this type may well cover practically every type, whereas the shell type varies in many ways and is a difficult piece of apparatus to assemble, especially in the larger sizes above 2,000 k.w.

Air-blast transformers are regularly built in capacities up to 4,000 k.w. and for a voltage of 33,000. Their efficiency, in good designs and with the required amount of air pressure, is slightly better than the oil-filled water-cooled transformer of the same capacity.

The general design is very much like the ordinary shell-type transformer with the exception of a few modifications in the iron assembly, where certain air spaces are left open for the circulation of air. The air-space area in these transformers is considerably in excess of the actual area required for the pressure of air specified for cooling. For this reason dampers are provided to regulate the air so that each transformer will receive its proportion. The air always enters the transformer at the bottom and divides into separate paths, flowing upward through the

coil ducts controlled by the dampers at the bottom of the transformer casing, and through the core ducts controlled by a damper at the side of the casing.

This type of transformer is always shipped already assembled, so that in the larger sizes great care is necessary in handling them. For shipment abroad the larger sizes would, of course, have to be dis-assembled, but this is of rare occurrence.

The transformers are fixed in position over an air chamber made of brick or concrete, the sides of which are made smooth so as to minimise friction and eddy currents in the air. The trunk from the blower should be as free as possible from angles, and where these must occur, they should be well rounded off. Sufficient space should be allowed to run the high- and low-voltage leads, and for all necessary repairs and inspection. Three-phase transformers have larger air chambers than single-phase transformers of the same aggregate capacity. The temperature of the outgoing air compared with the temperature of the ingoing air is the best indication whether sufficient air is passing through the transformers; if there is not more than 20° C. difference, the supply of air will be found sufficient. As transformers are generally designed on the basis of 25° C., the best results are obtained when the temperature of the incoming air is not greater than this value.

Installation of Transformers.—In the installation of high-voltage transformers of the self-cooled oil-filled, water-cooled oil-filled, forced oil-cooled oil-filled, and the air-blast types, it is thought that the following suggestions may cover some of the most important points which are apt to be neglected :—

(*a*) In generating and receiving stations the transformers should be so situated that a burn-out of any coil, boiling over of the oil, or burning of the oil in any unit will not interfere with the continuity of service.

(*b*) In generating and receiving stations the transformers should be so located that the high-voltage wiring from transformers to bus-bars is reduced to a minimum.

(*c*) The transformer tanks, which must be made of a metallic or non-combustible material, should be permanently and effectively grounded, preferably to the cables to which the station lightning arresters are connected.

(*d*) Sufficient working space should be allowed around each unit to facilitate repairs and for necessary inspection.

(*e*) During the entire process of installation of high-voltage transformers, the best workmanship is of utmost importance.

(*f*) Very special care and knowledge are necessary on the part of those whose duty it is to dry-out transformers, for the difficulty is not so much in drying the coils, but in drying the whole insulation surrounding them and the core. No matter for what factor of safety the transformer has been built, it avails little in the case of carelessness or neglect to dry-out the transformer properly.

Before transformers leave the factory they are given a high-voltage test, the standard being to apply twice the rated voltage between the high- and low-voltage windings, the latter being connected to the iron core. The main object of applying this test is to determine whether the various portions of the coils are properly insulated from each other. It is now believed that the greatest cause of failure in high-voltage transformers arises from punctures between turns and not between the high- and low-voltage windings.

To install properly and place in good working order high-voltage power transformers is quite as important a matter as their design, since upon this the life of a transformer depends. All transformers should be thoroughly dried out on arriving from the factory, and it is of course needless to say that all transformers which show evidences of being unduly moist, or that they have been subjected to conditions which would cause them to be unduly moist, should be taken special care of in the drying process.

Before a high-voltage transformer is put into operation it is made subject to a "heat run," and in the case of a transformer with cooling coils, the coils are made subject to a pressure test. These coils must be assembled before the heat-run can be made. If the coils show evidence of rough usage, such as heavy indentations and disarrangement of layers, they should be given the usual tests to determine whether a leak has resulted. A test for leaks is to fill the cooling coil full of water, establish a pressure of 80 to 100 lbs. per square inch, disconnect the source of pressure, holding the water in the cooling coil by means of a valve, and to note whether the pressure gauge between the valve and the cooling coil maintains its reading throughout a period of about one hour. Care should be taken that no air is left in the cooling coil when filling it with water. In removing the pressure it is preferable entirely to disconnect from the cooling coil, in order both to make sure that the source of pressure is entirely removed and to note whether the lowering of the pressure indicated by the gauge connected to the cooling coil is due to leakage through the cooling coil valve or to leakage through a hole in the cooling coil. If the gauge indicates a lowering of pressure in the cooling coil, and there is no evidence of leakage at either end of the coil, it should be inspected throughout its length until the hole is discovered. The water will gradually form at the hole and begin to drip. After the cooling coil is filled with water, a small air-pump may be used for giving the required pressure, in case there is not a satisfactory head from the water supply. As the test is only to determine whether the cooling coil has a leak in it, it will be unnecessary to apply a greater pressure than 100 lbs. per square inch. Some engineers prefer to submerge the cooling coil in a liquid, under an air pressure of 80 to 100 lbs. per square inch for a period of about one hour, and note if bubbles rise to the surface.

Several methods exist for drying out high-voltage transformers, the best being as follows:—

1. Short circuit either the high- or low-voltage windings, and apply

sufficient current to raise the temperature of the windings to approximately 80° C. The amount necessary to obtain this temperature will be between one-third and one-fifth of the full-load current, depending on the room temperature and the design of transformer. The impedance voltage necessary to give the specified range in current varies from 0·4 per cent. to 1·5 per cent. of the rated voltage of the winding to which the voltage is applied. In any case, the current admitted must be so regulated that the temperature of the windings does not exceed the 80° C. limit.

The temperature of the transformer windings may be determined by the increase in resistance, or, if facilities for this method are not available, the bulb of a spirit thermometer may be placed in direct contact with the low-voltage winding at the top. A low-voltage winding is specified for the reason that to place the bulb of the thermometer in contact with the high-voltage winding may not give the temperature of the coils; the insulating pieces set around the ends of the high-voltage coils being built up on the copper under the tape to such a height as to prevent the thermometer recording the temperature of the copper. The bulb of the thermometer should be placed down between the low-voltage coils as far as possible, that is to say, as far as the space between the coils will permit, the bulb of some spirit thermometers being too large for the space. Mercury thermometers must never be used for this purpose, because of their liability to break. The drying process should be carried on while the transformer is out of its tank in order to give as good a circulation of air as possible under the conditions. Table IV. is considered to represent the safe limits for carrying on the drying process, although discretion must be used as in the case of unduly moist transformers, or where the kilowatt capacity and voltage enters into consideration. That is to say, a transformer of 44,000 to 70,000 volts, and 200 k.w. and less, can be taken as safe if the heat-run period is only carried on for 60 hours instead of 72 hours, or a transformer of 22,000 to 33,000 volts, and of 200 k.w. or less, may be considered safe if the heat-run period is only carried on for 24 hours instead of 48 hours, assuming the transformers to be in normal condition.

It is impossible to give anything but an approximate estimate of the number of hours necessary to dry-out a transformer of a given size and voltage. Much will depend on the condition of the transformer when it is received from the factory, whether in an unduly moist condition or dry.

2. A second method is to dry the transformer and oil simultaneously under the effects of heat and vacuum, the transformer being dried inside of its tank. The tank is first made vacuum tight (this being, in the majority of cases, a difficult task to do, and only accomplished after considerable time has elapsed with the vacuum pump under operation), by closing the holes indicated by the whistling noise of the entering air. The leaks are stopped by using putty, which should be fairly stiff in order to keep it from being drawn into the tank. If this

is done a day or two before the drying process is begun, thus giving the putty a chance to harden, it will be found much easier to obtain the required vacuum.

One of the transformer windings is short-circuited as in the first method, although the actual temperature in this case is allowed to reach 90° C. instead of 80° C., and the temperature is determined by the increase in resistance. The temperature of the oil should be maintained at approximately 80° C. during the drying process. When starting the heat-run it is found advantageous to bring the temperature up quickly, and to do this, full-load current may be applied until the

TABLE IV.

*Approximate Hours necessary for Drying-out High-voltage Power Transformers.**

Voltage of System.	Hours of Run.	Kilowatt Capacity.
22,000 to 33,000	36	200 to 500
" "	48	500 " 1,000
" "	60	1,000 " 2,000
" "	72	2,000 and above
33,000 to 44,000	52	200 to 500
" "	64	500 " 1,000
" "	72	1,000 " 2,000
" "	84	2,000 and above
44,000 to 66,000	64	200 to 500
" "	72	500 " 1,000
" "	84	1,000 " 2,000
" "	92	2,000 and above
66,000 to 88,000	84	500 to 1,000
" "	96	1,000 " 2,000
" "	118	2,000 and above
88,000 to 110,000	96	500 to 1,000
" "	118	1,000 " 2,000
" "	130	2,000 and above

approximate temperature is reached, after which it should be reduced to the specified value. In addition to heating by current a certain amount of heat should be applied under the base of the transformer. The most satisfactory method of applying heat to the base is to use grid resistances supplied with sufficient current to maintain them at full red heat. The grids should be distributed under the base so as to make the heating fairly general, and not confined to one portion of the surface. In case some other method of heating the base is used, extreme care should be taken that the heat does not become

* These specified limits of hours refer to the time that the process must be carried on after the oil has reached a temperature of 80° C., and after a vacuum of 20 in. has been established, and do not refer to the time necessary to reach the 80° C. point and 20 in. of vacuum.

too intense, otherwise the oil might be injured. The idea of supplying heat to the base is to maintain the temperature of the oil throughout the transformer structure at a uniform temperature of 80° C. It is found that the temperature of the windings reaches 90° C. considerably in advance of the oil reaching 80° C.; and, for this reason, it is necessary either to disconnect the current occasionally or to reduce it to a small proportion of full-load current. The base heating should be relied upon to maintain the oil at a temperature of 80° C. as long as it will, which may be almost constant, provided a sufficient quantity of heat is applied.

When current is not available, steam at a low pressure may be used for heating, the steam being admitted through the cooling coil. Also, steam may be used for the base heating; in which case the entire bottom surface of the base should be subjected to the heat of the steam. Care should be taken in admitting steam through the cooling coils that the temperature of the oil does not exceed a prescribed limit. This method of applying heat at the base is not recommended, principally because the steam condenses on all parts of the transformer tank.

3. This method of drying transformers requires the circulation of heated air through the transformer coils and core while it is in the tank. The source of the heated air should be connected to the base valve and the top cover of the tank partly removed. The temperature of the air inside the tank should be maintained at approximately 80° C., and the process should be carried on at this temperature for a period of three days for units of moderate size, the same discretion being used as mentioned in the first and second methods. The temperature of the heated air as it enters the transformer should not exceed 100° C. This method of drying transformers is especially adapted to localities where no current is available.

The oil may be dried by the vacuum method mentioned in the second method, or by blowing heated air through it, referred to in the third method. Where the vacuum method is used, the tank must be filled to within a few inches of the top, so that the cover may be kept sufficiently warm to prevent condensation. In case the tank without its transformer is used for this purpose, it is sometimes necessary to put temporary bracings inside the tank to prevent collapse under vacuum. This does not refer to tanks of the cylindrical form. A 12 hours' run under a temperature of 80° C., with not less than 20 in. of vacuum, should be quite sufficient to dry transformer oil. All large installations are provided with cylindrical tanks for this purpose.

An energy meter may be fixed at the bottom of the tank, and assuming that the tank in which the oil is being dried will radiate approximately 0·25 watt per square inch, the amount of energy required to maintain the oil at the specified temperature may quite easily be estimated. The electric heater should be about double the size estimated so as to shorten the time necessary to reach the desired temperature. Whether a steam coil or an electric heater is used, it must be placed directly on the bottom of the tank, as it is

necessary to maintain a uniform temperature of the oil throughout. In case steam is used, its pressure should not be greater than 10 lbs.

The same tank may be used for drying oil by means of forced circulation of air. In this case it is necessary to run the piping from the valve in the base of the transformer above the oil level, and then down to the air-pump, the top of the tank having an adjustable opening to permit the air to circulate. The oil must be heated to a temperature of approximately 100° C., and the process continued until the oil becomes dry (as determined by test), which may take from 12 to 24 hours.

In the air-blast transformer careful examination should be made about once a month to see that the air-circulation ducts are quite free from the accumulation of dirt and dust. In the case of oil-cooled transformers, samples of the oil should be drawn from the bottom of the tank about once a month and tested, and a record kept of its condition. Where transformers are not used very often or where the current has been shut off for some time, the oil in the transformers designed for voltages of from 44,000 to 110,000 volts should be kept slightly warm, in order to eliminate the chance of the oil becoming moist. In fact, it is desirable, for the purpose of preventing condensation on the oil surfaces and other inside transformer surfaces, to keep the oil at all times at least 10° C. above the room temperature.

TABLE V.

Oils for High-voltage Transformers.

	Quality (A).	Quality (B).
Flash-point	185° C.	129° C.
Fire test	210° C.	149° C.
Viscosity	105 seconds for (A)	39 seconds for (B)
Breakdown test ...	30,000 volts	40,000 volts

Transformer Oil.—As the subject of treating transformer oil and the properties of oils is so broad, and has been treated in a thorough manner by other writers, only a few important notes are referred to here.

The most important characteristics of transformer oils which interest the operating engineer are summed up in Table V.

These values are a standard minimum for 0·2 in. gap. Quality (A) is for oil-cooled, and (B) for water-cooled transformers.

At a temperature somewhat below the fire test shown above, the oil begins to give off vapours which, as they come from the surface of the oil, may be ignited in little flashes or puffs of flame, but the oil itself will not support combustion until it has reached the temperature of the fire test as above. The lowest temperature at which these ignitable vapours are given off is called the flash-point. The difference between "flash-point" and "fire test" varies considerably in different oils, and the actual location of the points themselves varies somewhat according to the method used in their determination. Both a high flash-point and a high fire test are very desirable in insulating oils in order that the fire risk attendant on their use may be reduced to a minimum. Viscosity and flash-point vary together; that is to say, an oil having a high flash-point, compared with another oil, will probably also be high in viscosity. For all transformers that depend entirely upon oil for dissipating the heat (as in the oil-filled, self-cooled type) a relatively high flash-point is of the utmost importance.

For oil-filled water-cooled transformers it is customary to use another grade of oil than that used in the self-cooled type, the oil

TABLE V.A.

Characteristics.	Oil (A).	Oil (B).
Flash temperature	188° C.	133° C.
Burning temperature ...	210° C.	146° C.
Freezing temperature ...	—10° C.	—16° C.
Viscosity	100 to 105 sec.	40 to 42 sec.
Specific gravity at 15·5° C. ...	0·868	0·850
Colour of oils	Dark amber	Similar to water

operating at a lower average temperature, consequently a high flash-point is not of so much importance. There are several grades of mineral oil with flash-points varying from 130° C. used in water-cooled transformers.

The most important characteristics of (A) and (B) transformer oils are given in Table V.A.

Usually oil is received abroad testing less than 30,000 volts per 0·2 in., but before it is placed into the transformer it is brought up to a test at least 30,000 volts per 0·2 in. for transformers designed for an operating voltage of 44,000 volts and under; not less than a 44,000-volt test per 0·2 in. is required for oil used in transformers operating above 44,000 volts.

The curve Fig. 6 shows very clearly the serious effects of water in amounts less than 0·010 per cent. It is shown that the water present must not exceed 0·001 per cent. in order to obtain a dielectric strength of 40,000 volts in the standard test (0·2 in. between 0·5 in. discs).

Blotting filter paper is now used to a great extent in drying oil and in cleaning oil for high-voltage transformers. The paper used should not come in contact with the hands and should be dried at least twenty-four hours at not over 85° C. and then saturated with dry oil the instant it is removed from the oven and before it has cooled. As the paper is weakened by drying and by saturating with oil, especially hot oil, it must be carefully handled.

Comparison of Shell- and Core-type Transformers.—Transformers of any type should not be selected at random, but only after careful investigation of their design, reliability, and simplicity for repair.

When we compare the shell type shown in Fig. 7 with the core type from the standpoint of operation, we find that there are several advantages in favour of the shell type.

In general the shell-type transformer is a difficult piece of apparatus to repair in case of breakdown, though not so difficult as it is often

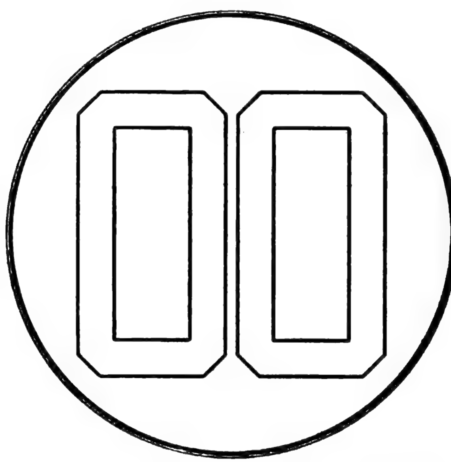


FIG. 7.—Single-phase Shell-type Transformer.

made out to be. The difficulty increases in almost direct proportion to the increased kilowatt capacity, and in the largest sizes it becomes advisable to send for a transformer man from the factory to do repairs. This disadvantage has been, and is to-day, considered the only cause of a number of power companies operating their lines at high voltages choosing the core-type transformer.

An experienced transmission engineer never fails to realise the severe conditions to which transformers are subjected in practice, and, especially for high-voltage transmission lines, seldom fails to go thoroughly into the factor of insulation, which to him means continuity and uninterrupted service. It is well known that the insulation

of a high-voltage transformer is subject to severe potential stresses, some of which are :—

(*a*) Sudden increase in generator voltage.
(*b*) Sudden increase in line voltage from local causes.
(*c*) Direct and indirect lightning discharges.
(*d*) Ground on one of the lines—depending on the connection.
(*e*) Internal or external arcing grounds.
(*f*) Line surges, etc.

Nothing but the very best insulation will satisfactorily withstand these stresses.

Reliable data taken from a number of electric power companies operating long-distance transmission lines show that the shell-type transformer has been more reliable than the core type for high-voltage service.

Some people think that once a transformer has been put into successful operation it will continue to operate satisfactorily for an indefinite time without any attention. This is a wrong idea. Transformers require attention, and must be given attention, or else they will not give good service.

A modification of the insulation on the end turns of core-type transformers has, however, given them a better standing, and they can now be depended on equally as well as the shell-type transformer.

Some of the most important advantages and disadvantages of these two general types may be summed up as follows :—

Advantages in favour of the Shell Type.

1. Greater radiating surface of coils and core resulting in a lower temperature in all parts of the transformer. This point has an important bearing on the insulation—the life of the transformer depending on the strength of the insulation of the hottest part.
2. Interlacing of coils, resulting in lower reactance voltages, hence closer regulation.
3. Mechanically stronger and more able to withstand the electro-magnetic stresses. As the electro-magnetic stresses are proportional to the square of the current, a short circuit of many times the normal full-load current will produce abnormal strains in the transformer.
4. Satisfactory series-parallel operation, this often being necessary on large transmission systems.

Advantage in favour of the Core Type.

Easier to repair.

Disadvantage of the Shell Type.

Difficult to remove a coil.

Disadvantages of the Core Type.

1. With low-voltage winding designed for 22,000 volts and above, the amount of insulation next to the core means a larger mean turn of winding, the temperature and the I^2R loss being increased thereby.
2. Radiating surface on the low-voltage winding very poor, resulting in higher temperatures. It is a disadvantage if, say, 90 per cent. of the transformer operates at a temperature of 50° C. and the remaining 10 per cent. at 80° C., as this point is the weakest link in the insulation.
3. The concentric arrangement of coils results in poorer regulation and higher reactance voltages.
4. Less mechanical bracing because of its design and form.
5. Not possible to operate a 3-phase (delta-delta) transformer in case one winding becomes damaged.

The terms "shell" and "core" mentioned will convey to the mind a definite conception of the construction. Some of the designs of the low-voltage transformers are so overlapped that what one manufacturer calls a shell type another manufacturer of a similar design calls a core type. The types referred to in this paper are of the rectangular shell and circular core construction only.

Operation of Transformers.—For several years past the corona discharges occurring in high-voltage transformers when connected to transmission lines have been studied, and numerous experiments have been made to avoid them. As the voltage increases this difficulty increases, and with such factors as the great length of high-voltage winding and small diameter of conductor in these windings, the matter is looked upon with much interest by transmission engineers.

The efficiency of a transformer is usually considered its most important feature by the majority of station engineers and managers operating local distribution systems. By transmission engineers this feature is not considered to be the most important, but rather the insulation of the transformer, and consequently its reliability. Unquestionably the efficiency of a transformer is an important feature and should not be neglected, but it cannot be considered as the most important feature of a large high-voltage transformer. The author believes the right order of importance to be :—

1. Reliability, or ability to supply continuous and uninterrupted service.
2. Safety, or a condition conforming with safety to life and property.
3. Efficiency.

Many breakdowns of large power transformers have been recorded resulting from the stoppage of the cooling medium, all of which could have been saved if proper care had been shown. Hourly temperature

readings are the best indications of anything wrong in this direction. As is well known, high-voltage transformers designed to operate with some form of cooling supply cannot run continuously, even at no load,

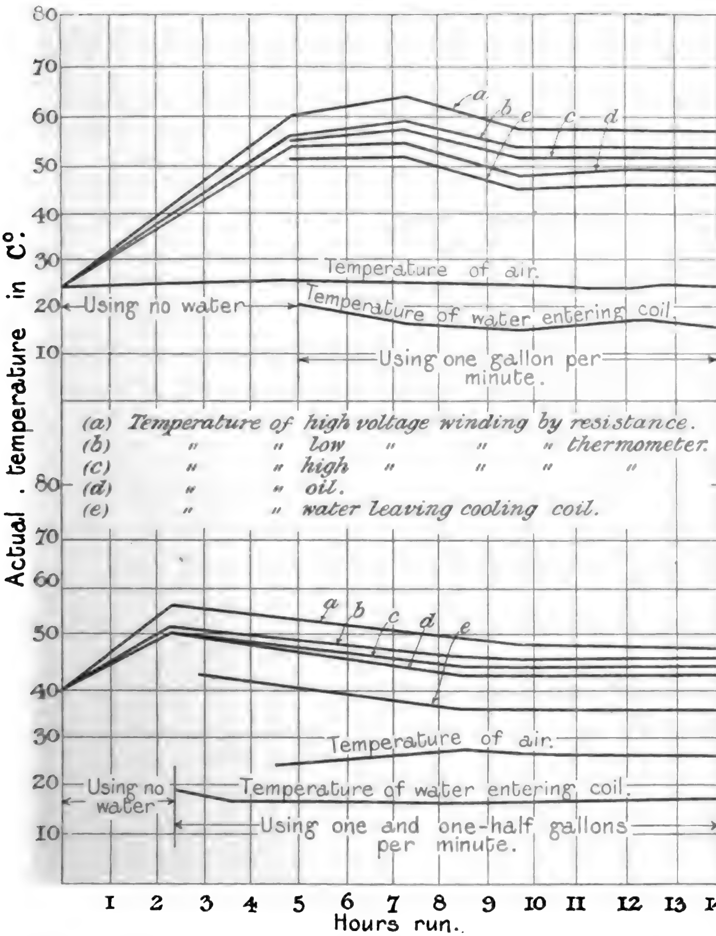


FIG. 8.—Result of Cutting off Water Supply of a 500–22,500-volt 25-cycle Transformer.

without the cooling medium, since the iron loss alone cannot be taken care of by natural cooling. In case the circulation has been stopped by any cause, the transformer may be operated until the coils at the top of the transformer, in case of an air blast, or until the oil, in case of a water-cooled transformer, reaches an actual temperature of 80° C.

This temperature limit, under ordinary conditions, will permit the transformer to continue delivering power for about three hours; a very close watch must be kept of the temperature, and the transformer must be taken out of service as soon as it reaches this limit.

Fig. 8 may be referred to in illustration of this.

The outfit shown in Fig. 9 has been the means of saving many transformers from burning-out. The water relay or balance is actuated by a volume of water in such a manner that if the water slacked off or

TABLE VI.

Modern High-voltage Power Transformers operating above 62,000 Volts.

Systems.	Kilowatt Capacity.	Voltage of Line.	Connection of System.	Phase ϕ.*
Stanislaus Power Company ...	3,750	138,500	Star	1
	2,233	104,000	Star	1
Great Western Power Company	10,000	110,000	Delta	3
	5,000	90,000	Delta	1
Grand Rapids Michigan Power Company	3,750	110,000	Delta	3
Hydro-Electric Commission ...	1,250	110,000	Delta	1
Great Falls Power Company ...	1,200	102,000	Delta	1
Central Colorado Power Company	3,330	100,000	Delta	1
Southern Power Company ...	3,000	100,000	Delta	1
Mexican Light and Power Company	6,000	85,000	Star	1
Telluride Power Company ...	1,500	80,000	Star	1
Edison Electric Company (Los Angeles)	1,660	75,000	Star	1
Pennsylvania Power Company	10,000	70,000	Star	3
Missouri River Power Company	1,500	70,000	Star	1
Southern Wisconsin Power Company	1,000	70,000	Delta	1
Connecticut River Power Company	5,000	66,000	Star	3
High Falls Development ...	1,100	66,000	Star	1
Canadian Niagara Falls Power Company	1,250	62,500	Star	1

ceased to flow, it would light the lamp. The bell alarm is so arranged that it will operate as soon as the temperature of the transformer, as indicated by the thermometer, reaches a certain limit.

In the operation of transformers the delta connection has an advantage. With one grounded conductor the service need not be interrupted, except perhaps if the ground is an arcing one, which might set up continuous high-frequency surges, producing high-voltage stresses on the transformers in circuit. Comparisons of different systems are shown in Table VI., which are representative of practically all the most modern high-voltage transformer installations in the

* This refers to the type of transformer whether single-phase or 3-phase.

world. There are one or two of equal importance under construction, but as these have not yet demonstrated themselves in practical operation, they have been omitted from the list.

Single-Phase versus 3-*Phase.*—As the art of transformer design and manufacture improves, the 3-phase transformer will be as extensively and universally used as the single-phase transformer for high voltages, its only disadvantage being in the case of failure and interruption of service for repairs; but this will be off-set by other important factors since breakdowns will be of very rare occurrence.

From the standpoint of the operating engineer (neglecting all losses) the single-phase transformer is at the present time preferable where only one group of transformers is installed and the expense of a spare transformer would not be warranted as in the delta-delta connected

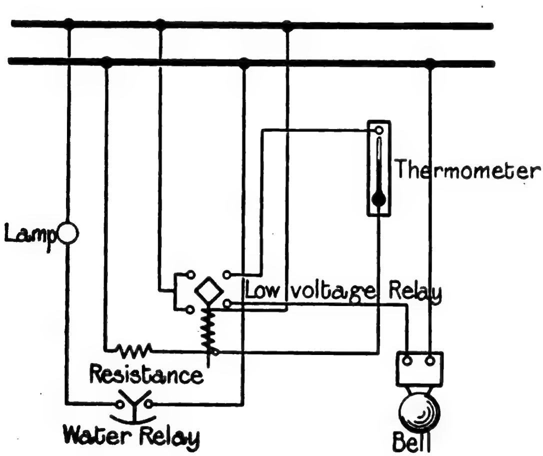


FIG. 9.—Water, Thermometer, and Bell Danger Indicator for High-voltage Transformers.

system. If one of the three transformers should become damaged it can be cut-out with a minimum amount of trouble, and the other two can be operated at normal temperature on open-delta at approximately 58 per cent. of the total capacity of the three. With a 3-phase transformer a damaged phase would cause considerable inconvenience, for the reason that the whole transformer would have to be disconnected from the system before repairs of any kind could be made.

In the absence of any approved device or apparatus to be relied upon to take care of high-voltage line disturbances such as occur on long-distance transmission lines, the whole burden is thrown on the insulation of the one important link of the system—the transformer. The 3-phase transformer is slightly handicapped, since a breakdown would entirely interrupt the service until a spare transformer was

installed or the faulty one temporarily arranged, with its faulty winding short-circuited, in the case of a shell type. The engineer who has the responsibility of operating high-voltage systems has not yet taken very favourably to the 3-phase transformer for this very reason and for no other reason, his main object being reliability of service and not the first cost or saving of floor space, and he has yet to be shown why reliability of service conditions should be sacrificed to gain that end and a slight increase in efficiency when the only important, or rather the most important, factor at stake is continuity of supply. Yet even to gain this end efficiency must not be neglected.

Many engineers who operate moderate-sized systems fail to see the all-important factor mentioned above, possibly because they are too taken up with such factors as decrease in cost, increase in efficiency, decreased weight, less floor space, decreased installation cost, and less freight cost. These, of course, are excellent points to bear in mind when investing in transformers, but the question often arises: Do they always outweigh reliability, flexibility, and simplicity of repair?

It has for many years been fully appreciated by European and American engineers that, apart from the decrease in manufacturing cost with increase in size of units, the 3-phase transformer possesses the advantage of requiring less material, and is more efficient than any other single-phase combination of transformers of the same kilowatt capacity; the relative differences in the losses and weight being approximately:—

Three single-phase transformers weigh 17 per cent. more than one 3-phase transformer.

Three single-phase transformers have 17 per cent. more losses than one 3-phase transformer.

Open-delta.—Two single-phase transformers weigh the same as three single-phase transformers for the same delivered energy in kilowatts.

Two single-phase transformers have the same losses as three single-phase transformers.

"*T*" *Tee.*—Two single-phase transformers have a sum total weight of 5 per cent. less than three single-phase transformers.

Two single-phase transformers have a sum total weight of 5 per cent. less than two single-phase transformers connected in open-delta.

Two single-phase transformers have 5 per cent. less losses than three single-phase transformers.

Two single-phase transformers have 5 per cent. less losses than two single-phase transformers connected in open-delta.

"*T*" 3-*transformer.*—Three single-phase transformers weigh the same as those for a delta or star system, or 17 per cent. more than one 3-phase transformer—the losses being the same.

Three single-phase transformers weigh 5 per cent. more than two single-phase transformers for the "T" (2-transformer) system—the losses being the same.

Three single-phase transformers weigh the same as two single-phase transformers for the open-delta system for the same delivered energy in kilowatts.

Where a large number of 3-phase transformers is installed in one building, say, three groups or more, there is unquestionably a great saving over any combination of single-phase transformers, and the possibility of using two sets out of the three, or three sets out of the four, and so on, offsets that all-important drawback—reliability—and places the 3-phase transformer on almost an equal footing in this respect with the three single-phase transformer combination. The building is thereby reduced by a considerable amount, less high and low-voltage transformer terminal insulator bushings, compartment insulator bushings, and busbar high and low-voltage insulators are required, besides simplifying the wiring lay-out in the station.

To fulfil the requirements of a 3-phase transformer using a combination of single-phase transformers it is necessary to use :—

BASIS : *One 3-phase transformer of* 100 *per cent. kilowatt capacity.*

Delta Connection.

Three of 33·3 per cent. each, or total 100 per cent. kilowatt capacity.

Star Connection.

Three of 33·3 per cent. each, or total 100 per cent. kilowatt capacity.

Open-delta Connection.

Two of 57·7 per cent. each, or total 115·5 per cent. kilowatt capacity.

"T" (2-transformer) Connection.

One of 57·7 per cent. kilowatt and one of 50 per cent. kilowatt, or total 107·8 per cent. kilowatt capacity.

"T" (3-transformer) Connection.

Three of 33·3 per cent. each, or total 100 per cent. kilowatt capacity.

From this we see that the three best combinations are delta, star, and the 3-transformer "T" connections. With the delta and the "T" (3-transformer) systems a spare transformer is not warranted, and in the case of a breakdown of one unit the minimum amount of time is lost in cutting it out of service. With the open-delta and "T" 2-transformer) systems, the loss of any unit stops the system from operating 3-phase current. A further advantage of the 3-transformer methods—delta, star, and "T" (3-transformer)—is, a spare unit costs less than one for either the open-delta or the "T" (2-transformer) methods.

Connections of Transformers.—In the connection of power transformers for high-voltage transmission systems there is a choice between two methods for the 3-phase system, namely, delta and star (see Fig. 10).

Where—

$x = y\sqrt{3}$, or 100 per cent.,

and—

$y = \frac{x}{\sqrt{3}}$, or nearly 57·7 per cent. of full voltage between lines in case of the star connection.

The delta connection, where $x = 100$ per cent., the voltage is that shown between lines.

For 2-phase 3-phase, there is a choice between two methods, namely, 3-transformer "T" and 2-transformer "T" (see Fig. 11).

Where—

$y = \frac{\sqrt{3}}{2} = 86{\cdot}6$ per cent. of the voltage between transformer terminals a, b, c.

$x = y\frac{2}{\sqrt{3}} = 100$ per cent., or full voltage between transformer terminals a, b, c.

$z =$ Full terminal voltage $a'\ b'\ c'$ corresponding to a ratio of 1·0–1·15 of a, b, c values.

The relative advantages of the delta-delta and delta-star systems are still disputed, and are open to discussion. Assuming no unusual phenomena, but simple regular operative conditions or ordinary breakdown of a unit or phase winding, the two principal advantages claimed for the two are respectively :—

Delta-delta (Non-grounded).—When one phase is cut out the remaining two phases can be made to deliver approximately 58 per cent. of the full load rating of transformer (in case of a 3-phase shell type) or transformers.

Delta-star (Neutral grounded).—Advantage of reducing the cost of high-voltage line insulators for equal line voltage, which is a very large item when dealing with long-distance high-voltage transmission systems, as their size need be only 57 per cent. of those used on a line with transformers connected in delta.

It is possible, under such conditions, to operate and deliver 3-phase current when either one phase or one line conductor is cut out.

Delta-delta Disadvantage.—Larger transformer or transformers and larger line insulators for the same line voltage.

Delta-star Disadvantage.—Not always in a position to operate when either one phase or one line conductor is cut out.

The question now arises—Which is the more economical system of connections to use? From the point of view of first cost, the delta-star is unquestionably the better, but from the other point of view, which is again of importance to the operating engineer—how will the first cost outweigh the disadvantage of operation as compared with the delta-delta? The difference will be largely governed by local conditions, and no definite system of connections can be given to suit all cases.

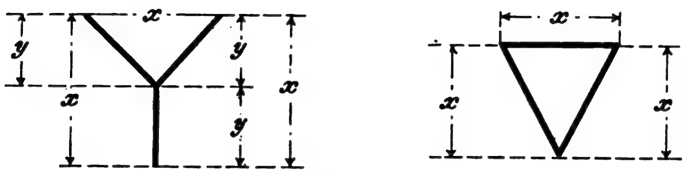


FIG. 10.

Assuming that the system of connections has been finally settled, the next problem, especially on large systems where a number of power companies have been consolidated, is that of parallel operation. In order to tie in a large number of local existing plants consisting of gas, steam, and water-driven generators, etc., with 2- and 3-phase distribution services, special care and thought are required in laying out the right scheme of connections. One is met with a 2-phase 3- and 4-wire city distribution and several other kinds of

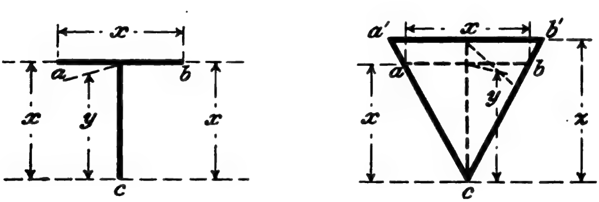


FIG. 11.

systems of odd voltages and frequencies which must be incorporated with the main high-voltage transmission lines through transformers and probably frequency changers, all of which require special knowledge on the part of those whose duty it is to operate them.

Consolidated systems of this kind generally have to contend with parallel operation of local power plants, this sometimes being done directly from the high-voltage side or line side of power transformers for voltages as high as 66,000 volts, by the application of potential transformers. Only a small number use this method of synchronising their auxiliary stations. Sometimes it is found necessary to tie-in a

distant hydro-electric plant of no larger size than 1,500 k.w. to a transmission system already carrying 45,000 k.w. and fully loaded at each generating station. A false move on the part of the operator in paralleling might very easily throw the entire system out.

It is also found advantageous on some occasions to parallel both the high- and low-voltage windings of power transformers; but to do this,

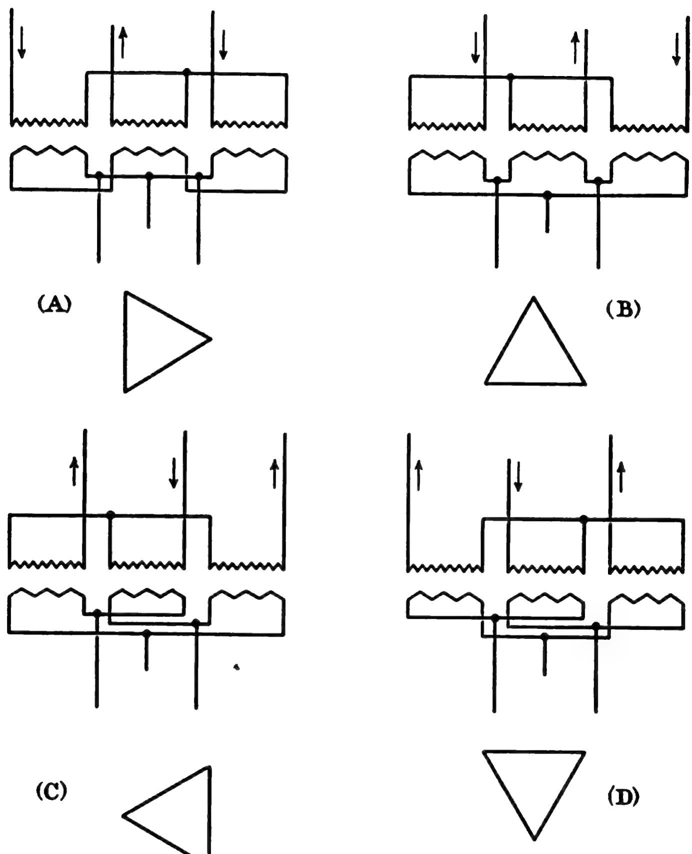


FIG. 12.—Three-phase Transformer Connections.

it is necessary to know the connections and voltages of the different transformer groups. With the delta and star systems, it is only possible to parallel *six combinations* out of the ten combinations so generally used. Of these six combinations the transformers to be paralleled must have equal impedance and equal ratio of resistance to impedance. With equal impedance the current in each unit will be in proportion to

the rated capacity in kilowatts, although the sum of the currents may be greater than the current in the line. If, on the other hand, the impedances of the units are unequal, the current in each unit will be inversely proportional to its impedance; that is to say, if one unit has 1 per cent. impedance and the other 2 per cent. impedance, the first unit will take twice as large a percentage of its rated capacity as the second unit; the sum of the currents in the two units may or may not be equal to the line current. With equal ratios of resistance to

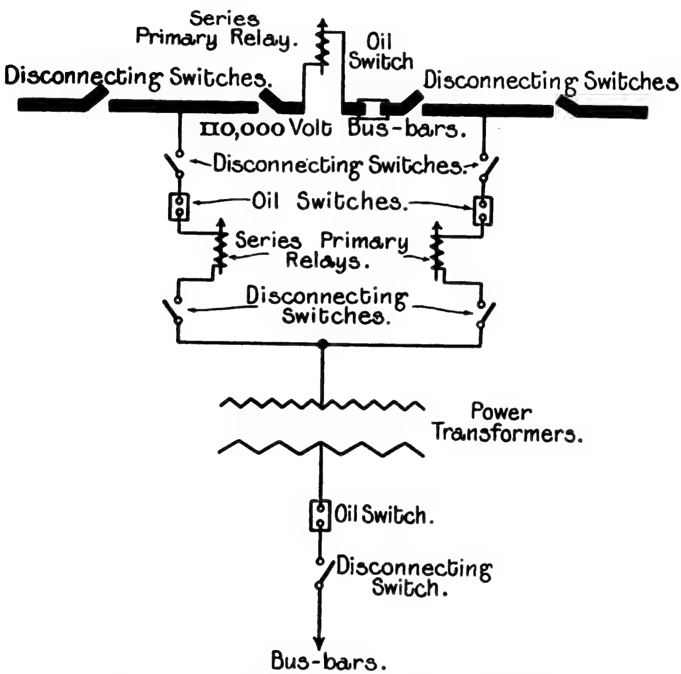


FIG. 13.—110,000 volt Transformer Protection.

reactance the current in each unit will be in phase with the current in the line, also the sum of the currents will be the same as the line current. With unequal ratios of resistance to reactance the current in each unit will not be in phase with the current in the line, therefore the sum of the currents will be greater than the line current. If, however, the impedances of the units are equal, both will carry the same percentage of full load current; and if, in addition, the ratio of resistance to reactance is the same in both cases, the current in the two units will be in phase with each other, and their numerical sum will equal the load current—thus we have a perfect parallel operation.

So far as the connections of a 3-phase or three single-phase transformers for delta or star are concerned, any of the combinations shown in Fig. 12 may be used as will be found convenient for any particular condition of station wiring lay-out. Whichever scheme of connections is decided upon it will be always found advisable to keep to that scheme throughout the system, otherwise complications might result. This is particularly applicable on some of the larger systems of 100 megawatts and over, where networks of high-voltage transmission lines and sub-stations are numerous.

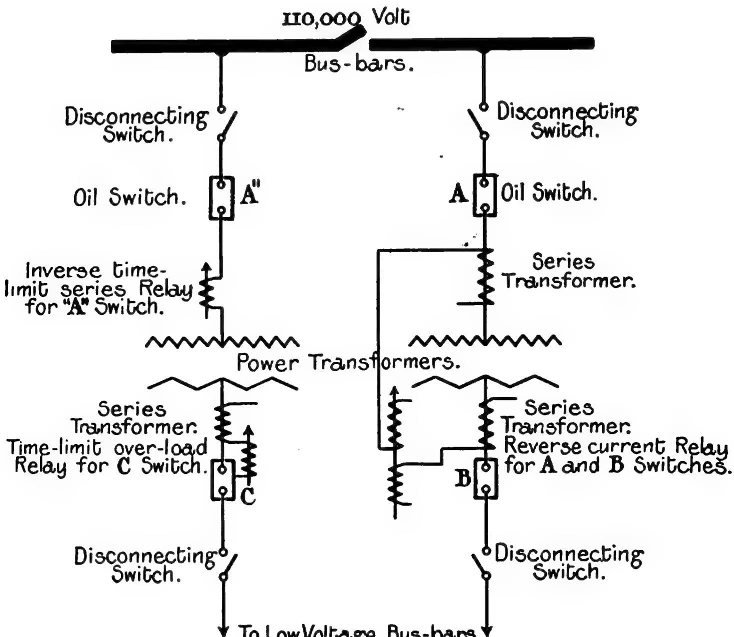


FIG. 14.—110,000-volt Transformer Protection.

Broadly speaking, large power transformers operating high-voltage transmission lines should be protected against excessive currents, and also against excessive voltage above normal. Some protective apparatus or device should be used even if it is only an overload device. Protection should be made against external and internal short circuits, such that the transformer will be disconnected in case of an internal short circuit, and that section of the transformer system relieved from any external short circuit. For external short circuits the external reactance is being favourably considered in limiting the flow of current.

Some of the protection schemes used at the present time are shown

in Figs. 13, 14, and 15. To those familiar with the practical operation of high-voltage systems it will be quite clear that to get absolute protection of a system of transformers from internal and external causes is difficult, and in some cases impossible.

In the case of a star-delta connected system—star-connected on the high-voltage side—it might be of considerable advantage to add

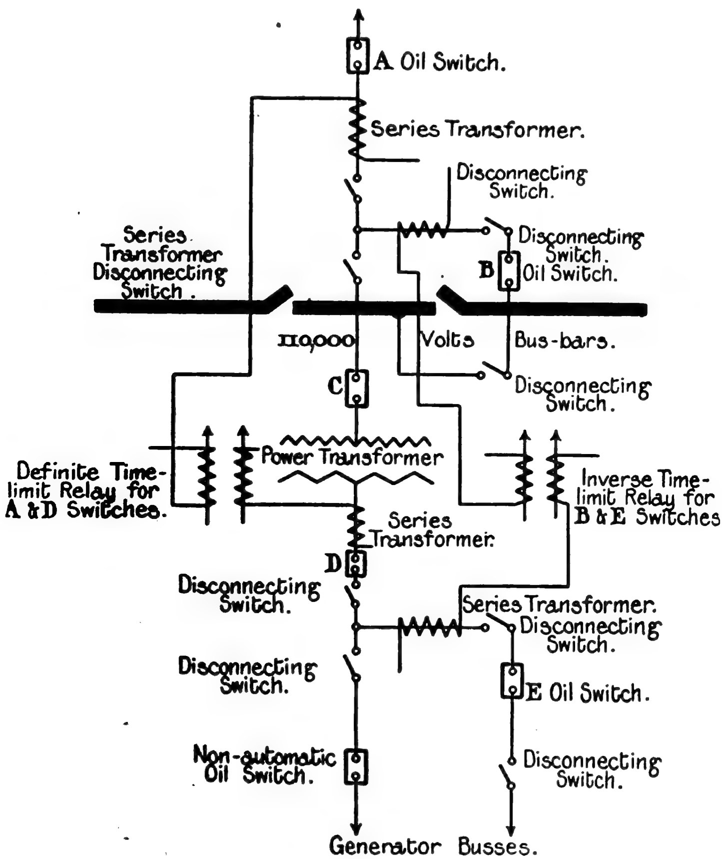


FIG. 15.—110,000-volt Transformer Protection.

resistance to the ground line of the neutral-point to reduce the rush of current in case of an external short circuit.

As steel towers are mostly used for high-voltage transmission, grounds are more common than with wooden poles. Such grounds either at the pole or directly in contact with the ground constitute a short circuit, and the easiest way to reduce the severity of a

short circuit is to add resistance in series with the ground circuit of the transformers. With a short circuit on the secondary of a transformer practically no magnetic flux flows through the secondary winding; and if the power system is sufficiently large to maintain constant voltage at the primary terminals of the transformer at short circuit, full magnetic flux flows through the primary winding; if the terminal voltage decreases at short circuit on the transformer secondaries, the magnetic flux passing through the transformer primaries decreases in the same proportion, and the mechanical forces in the transformer decrease with the square of the primary voltage.

Quite a number of systems have distant sub-stations with only two groups of transformers, both groups being operated in parallel at all

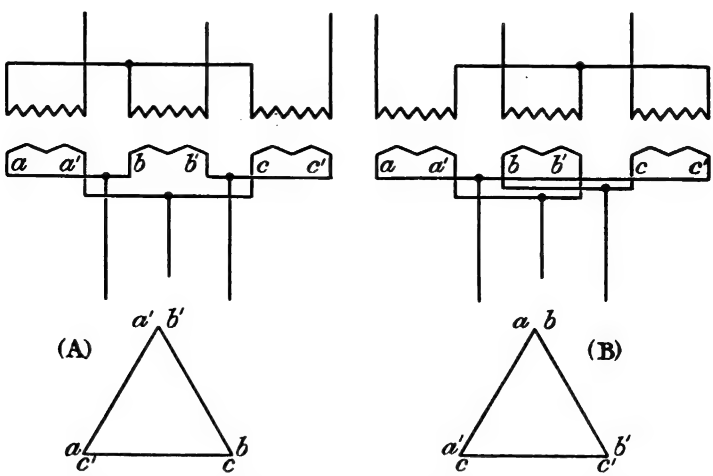


FIG. 16.—Uncommon Parallel Operation of Transformers.

times. Assuming the transformers to be connected in delta-delta and one transformer of one of the groups becomes damaged it might mean, if the load is great, that the other two of the same group have to be cut-out of service. Under ordinary conditions it is possible to operate three single-phase transformers connected in delta-delta with two single-phase transformers connected open-delta. It is also possible to operate the combination shown in Fig. 16, (A) with (B) of same figure.

Such transformer combinations as shown in Figs. 17 and 18 might be used for open-delta and star connections, respectively. Because of the possibility of crossing connections and having certain transformer windings wound in different directions, it is always advisable to keep to one kind of connection throughout the system, thus avoiding any complications.

Three-phase 2-phase.—The more we centralise electric power systems the more we shall require this method of distribution, which will come about through the transformation from 3-phase high-voltage transmission lines, this being at the present time the only system employed and recommended for long-distance transmissions—direct current not being applicable in such cases because of its expense in conversion and transformation, etc. Already several installations of this kind have been made and are operating satisfactorily

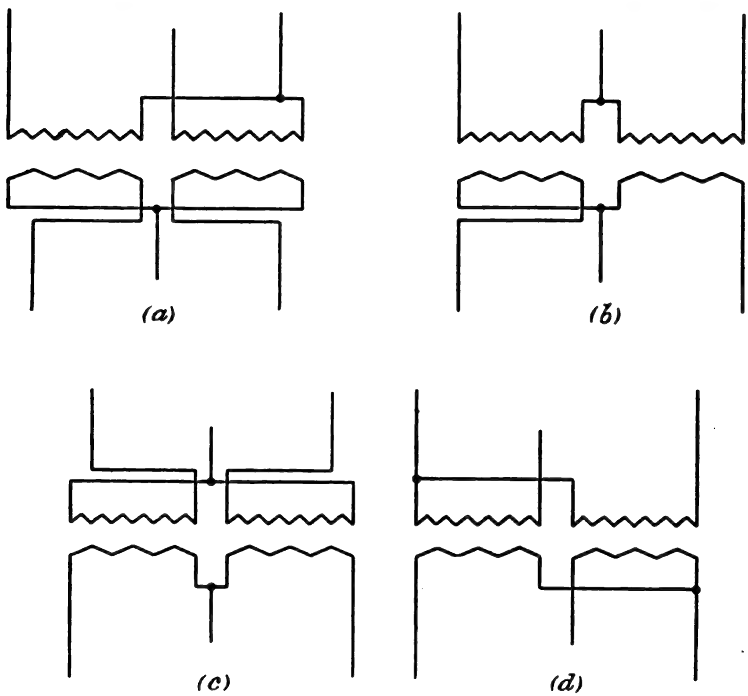


FIG. 17.—Open Delta Transformer Combinations.

at voltages as high as 60,000 volts, and there is every reason to believe the practice will become more general in the near future.

In the arrangement of the 2-transformer method of 2 to 3-phase transformation there are two independent magnetic circuits, and on the 2-phase or secondary side two windings with N turns each (Fig. 19). With the ratio of 1 to 1 the winding (B) has n turns; the winding (A) having n' or $\frac{2n}{\sqrt{3}}$ turns.

Transformers are usually built with 50 per cent. and 86·7 per cent. taps, and are thus interchangeable. When transforming from

3-phase to 2-phase proper interlacing of the primary windings should be made to eliminate leakage flux and improve the regulation. Serious unbalancing is sometimes due to excessive leakage flux caused by different power-factor currents circulating in the two halves of (A) winding (Fig. 19). Currents of different phase relation flow in the two halves of (A). In one, one-half the current is leading by 30° and in the other half lagging by the same amount, which, of course, results in different regulation in the two parts. If the currents I′ and I″ are equal and in time-phase—that is, both flowing simultaneously towards or away from the point 0—the resultant M.M.F. will be zero. If the currents are equal but opposite in time-phase, the M.M.F. in ampere-turns will be n' I″. In the former case, the two currents taken

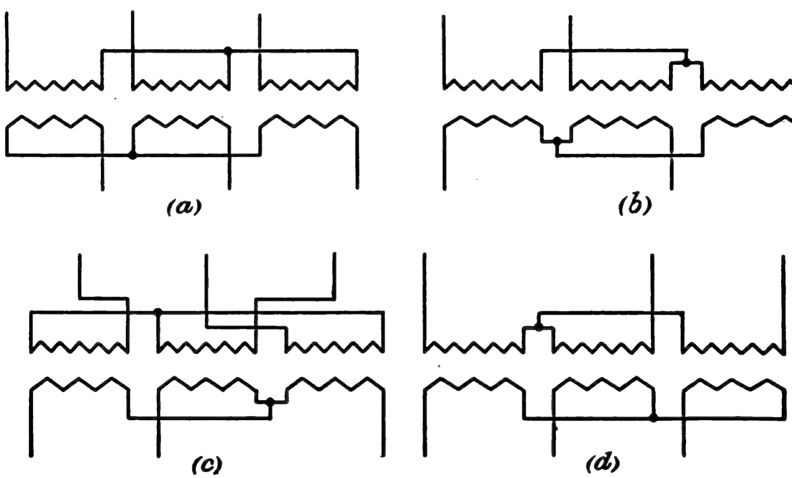


FIG. 18.—Star Transformer Combinations.

together represent no power, whereas in the latter the power is I″ E′ cos ϕ.

The voltage across one transformer winding is only 86·7 per cent. of that across the other, so that one has a kilowatt capacity of E I cos ϕ, and the other a rating of E I cos ϕ 0·867; the total rating being about 8 per cent. larger than the combined rating of three single-phase transformers connected in delta, star or "T" (3-transformer), and about 7·7 per cent. smaller than two single-phase transformers connected in open-delta.

It is well recognised that any combination of the 2-transformer method requiring a change from 3-phase to 2-phase, or from 2-phase to 3-phase, is made at the expense of regulation as well as involving a loss in efficiency. And, if the connection is used to step-up from 2- to 3-phase, similar connections should be arranged for stepping-

down at the receiving-end; in this way the possibility of cross-currents or asymmetry will be greatly avoided.

To reduce the effects of unbalancing of the 2-transformer system, it has been found necessary to:—

(*a*) Properly interlace the transformer windings on the low-voltage side if stepping-up, and high-voltage winding if stepping-down.
(*b*) Connect in multiple the two halves of windings, or use four instead of two transformers.
(*c*) Use three single-phase transformers.

Also, the question often arises whether to ground the neutral-point X, shown in Fig. 19, or leave it ungrounded. The advantage of grounding the neutral-point is the same as found in the star system—

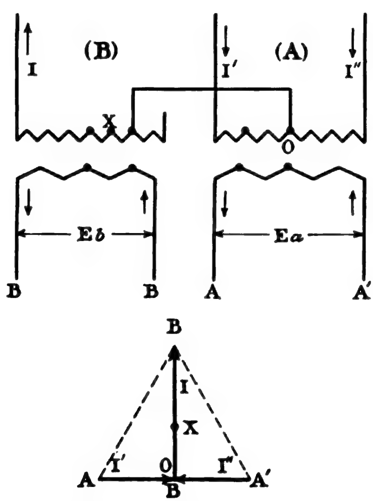


FIG. 19.—"T" 2-transformer Method.

i.e., a ground on one transmission line wire short circuits that phase and causes a complete shut-down; but when operating without the neutral grounded on the transmission-line side, the stress on the transformer insulation might be equal to full-line voltage. Of course, with grounded neutral and usual conditions of operation, the maximum insulation strain will only be 58 per cent. of full-line voltage. In general, the neutral-point of transformers is not grounded on the transmission-line side because of this danger.

Three-transformer Method "T."—Within the author's knowledge this system has never been described before any society or institution, and it seems to possess such good merits over the old method of transformation that a mention of it in a paper of this kind may lead to valuable

suggestions. It is used in various parts of America and for voltages as high as 33,000.

Continuity of service is now one of the main factors to be aimed at, and the 3-transformer method shown in Fig. 20 is in some respects a superior system to the 2-transformer method. If one of the transformers in the 3-transformer system should become damaged, making it inoperative, the two remaining transformers may be, in a very short space of time, temporarily connected in open-delta and service continued until the other is repaired, thus avoiding the necessity

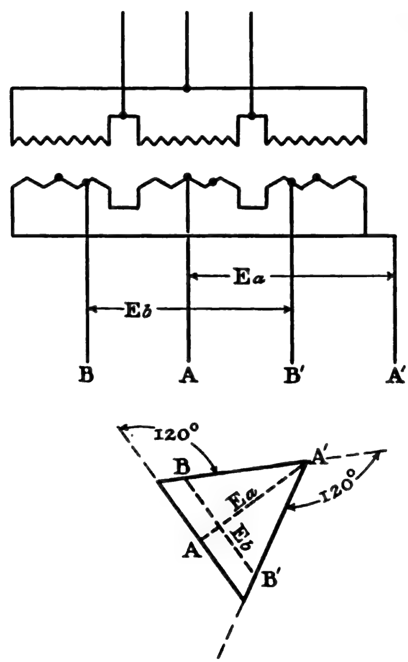


FIG. 20.—"T" 3-transformer Method.

of carrying a spare transformer in stock. And if a transformer is kept in stock its kilowatt rating need only be approximately 67 per cent. as great as a spare transformer for the 2-transformer system.

This system was only applied to practical city distribution a short time ago, and it is surprising what great strides have been made. It also claims the advantage of supplying both 3-phase and 2-phase currents to a secondary distribution of four wires, this being a special advantage in cities where there already exist two or more electric power companies operating both 2- and 3-phase systems, as no transformers are required for connecting either a 3-phase or a 2-phase motor.

The four combinations of 3-phase transformation shown in Fig. 21, (a), (b), (c), and (d), represent a few connections for 3-phase 2-phase systems using three transformers. The only one used for regular distribution of power and light is (a) ; the methods (b), (c) and (d) are only used for special purposes, such as for obtaining a certain voltage and phase relation for a given service.

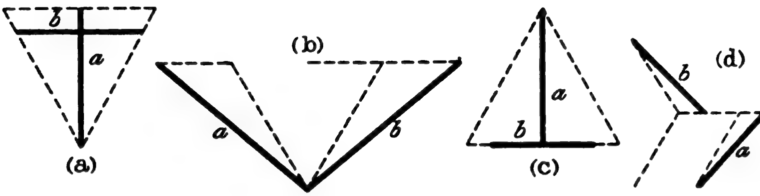


FIG. 21.—Three-transformer Methods.

From the point of view of reliability of operation the 3-transformer system has far greater advantages than the 2-transformer system, chief among which are :—

1. Larger factor of safety for continuity of service.
2. With one transformer disabled the system can still be operated.
3. A spare transformer need not necessarily be kept as a spare.
4. A spare transformer need only have a rating of about 67 per cent. of that of a spare transformer for the 2-transformer system.
5. Symmetrical 2-phase and 3-phase voltages obtainable from the same winding.
6. Improved regulation and efficiency.
7. Better balancing of voltages under load.
8. For the same total kilowatt rating, only a ratio of 100 to 108 in favour of the 3-transformer system is required.

Its disadvantages from the standpoint of first cost and available connections for apparatus are :—

1. The first cost is higher.
2. It is not possible to operate interconnected motors and generators on the 2-phase secondary system.
3. Greater floor space and wiring are required.

Conclusion.—It is feared by some transmission engineers that the high-voltage transformer will again become the limiting feature of high-voltage transmission because of the internal effect due to corona. This effect so far has not been very noticeable, but as line voltages are increased above present-day practice (110,000 volts) certain effects due

to this discharge may arise which may radically change the present methods of design in high-voltage transformers. Some little fear is also attributed to certain conditions of electrostatic capacity and inductance in long lines with transformers at different points, for with transformers having a length of over 10 miles of wire connected across the line a certain operation of switches, atmospheric conditions, arcing "grounds," switching heavy loads, etc., may produce very strange and sometimes dangerous phenomena.

The present high-voltage power transformer is unquestionably the most efficient piece of electrical apparatus connected with an electric system. There is no single piece of electrical apparatus built which holds so important a part on transmission systems as this, and no piece of apparatus more dangerous to life and property should certain break-downs occur. Even transformers switched upon an open line of great length, and afterwards switching the transformers at the end of the "live" line, have caused peculiar phenomena, and sometimes break-downs of transformer insulation. This is the main reason why, whenever possible, transmission engineers recommend switching-in first the transformers at the far end of the line and afterwards the transformers at the generating station.

Of late, engineers have been devoting their time to power-limiting devices for large power transmission systems. With the large systems now being operated, consisting of 100 to 150 megawatts in generator and transformer capacity, hundreds of miles of transmission lines supplying thousands of customers of all classes, maintenance of a very high degree of reliability is the principal problem of the engineer. The question now before us is that of limiting the amount of energy which can flow during a fault or short circuit, and the only real practical solution applied so far is by the use of reactances, which, as we all know from more or less past prejudice, is the enemy to voltage regulation. The disastrous results of a short circuit on large power systems make it in some cases impossible to operate switches as the current and power behind are so great. Take, for instance, a system operating at 100 megawatts when a momentary short circuit occurs on the transmission line drawing, say, twenty times the full load current; it is obvious that, with good regulation of prime mover, generator, and transformer, the maximum current which could momentarily appear would be in the neighbourhood of 2,000,000 k.w.

Many power companies when ordering large power transformers expect the manufacturer to specify the minimum regulation. The tendency at the present time with the larger power systems is to allow for a greater margin of regulation by installing separate reactance in the line when transformers have low inherent reactance. The advantage of this is quite apparent when we consider a system of transformers connected to a set of busbars having a total generator capacity far in excess of the transformers. A minimum value of 1·5 to 3·5 per cent. regulation might, in the case of a short circuit on the secondary side of one of the transformers, cause sufficient

current to flow and to produce such electromagnetic stresses as to bend the iron and coils out of shape and destroy the transformer.

The experience of recent years seems to point out that the larger we build our stations, machinery, and apparatus, the better results we get. Not very long ago the economical limit placed on the size of a station was in the neighbourhood of 20,000 k.w., but to-day there are stations equipped with machinery and apparatus of practically 200,000 k.w. Transformers of 10,000-k.w. capacity are more economical than units of 5,000 k.w., and a system using ten 10,000-k.w. transformers is more economical than another using twenty 5,000-k.w. transformers.

APPENDIX I.

General Specifications for a 70,000-volt 25-cycle "Core-type" Oil-cooled Single-phase Transformer.

Core.—The cores to be built up with laminated iron sheets of high permeability, low hysteretic loss, and not subject to appreciable magnetic deterioration. The sheets to be carefully annealed and insulated from each other in order to reduce eddy current losses.

Windings.—The primary and secondary windings to be thoroughly insulated from each other and from the core and frame, and to stand a potential much greater than the rated voltage of the transformer.

Oil.—Each transformer to have sufficient oil to cover the core and winding when placed in the tank. The oil to be specially treated and refined in order to secure good insulating qualities and a high flashing-point.

Terminals and Connections.—The primary and secondary leads to be carefully insulated and taken from the tank through porcelain bushings, which shall have sufficient surface to prevent perceptible leakage to the frame of the transformer.

Performance.—After a run of twenty-four hours at rated load, voltage, and frequency the rise in temperature of any part of the transformer as measured by thermometer, and of the coils as measured by the increase in resistance, not to exceed 45° C., provided the temperature of the surrounding air is not greater than 25° C. and the conditions of ventilation are normal. If the temperature of the surrounding air differs from 25° C. the observed rise in temperature should be corrected by 0·5 per cent. for each degree.

Insulation between the primary winding and the core, and between the primary and secondary windings, to stand a test of 140,000 volts alternating current for one minute, and between the secondary winding and the core a test of 10,000 volts alternating current for the same length of time.

The transformer to carry an overload of 50 per cent. for two hours without undue heating of any of the parts.

General Specifications for a Rectangular "Shell-type" Water-cooled Oil-filled 70,000-volt 25-cycle Single-phase Transformer.

General Construction.—Each transformer to consist of a set of flat primary and secondary coils, placed vertically and surrounded by a built-up steel core, the coils being spaced so as to admit of the free circulation of oil between them, which acts not only as an insulator but as a cooling medium by conveying the heat from the interior portions of the transformer to the tank by natural circulation.

The transformer to be enclosed in a boiler-iron tank, the base and cover being of cast iron. The tank to be secured to the base with a joint made oil-tight by heavy riveting and caulking.

A coil of pipe for water circulation to be placed in the oil in the upper part of the tank over the cover and surrounding the ends of the windings, the combined surface of the coil and tank being sufficient to dissipate the heat generated and thus maintain the oil and all parts of the transformer at a low temperature.

Core.—The core to be built up of steel laminations of high permeability and low hysteresis loss. The laminations also to be carefully annealed and insulated from each other to reduce eddy-current losses.

Windings.—The primary and secondary windings to be subdivided into several coils, each built up of flat conductors, wound with one turn per layer so as to form thin, high coils which will present a large radiating surface to the coil. The conductors to be cemented together with a special insulating compound, after which an exterior insulating wrapping to be applied and separately treated with an insulating varnish, making a very durable insulation.

A solid insulating diaphragm to be placed between adjacent primary and secondary coils, and to be rigidily held in position by spacing channels covering the edges of the coils.

The assembled coils, except at the ends, to be completely enclosed by sheets of solid insulation, which will interpose a substantial barrier at all points between the winding and the core.

Oil.—Each transformer to have sufficient oil completely to immerse the core, windings, and cooling coil. In order to secure the best insulating qualities and a high flashing-point, the oil to be specially refined and treated and tested for this use.

A valve for drawing off the oil to be located in the base of the tank.

Water-cooling Coil.—To consist of heavy wrought-iron lap-welded pipe with electrically welded joints, and to stand a test of at least 1,000 lbs. pressure per square inch.

The duty of the cooling coil is to absorb that portion of the heat that cannot be dissipated by natural radiation from the tank, which will be made to fit the transformer closely, and thus minimise the amount of oil and floor space.

Leads.—The primary and secondary leads to be brought out through the cover, and to consist of heavy insulated cables brought through porcelain bushings of ample surface and thickness.

Performance.—After a run of 24 hours at rated load, frequency, and voltage, the rise in temperature of any part of the transformer, as measured by thermometer, and the rise in temperature of the coils, as measured by the increase in resistance, not to exceed 40° C., provided the temperature of the circulating water is not greater than 25° C., and that the supply of water is normal. If the temperature of the water differs from 25° C., the observed rise in temperature should be corrected by 0·5 per cent. for each degree.

The insulation between the primary coils and the core, and between the primary and secondary coils, to stand a test of 140,000 volts alternating current for 1 minute, and between the secondary coils and the core a test of double the normal voltage for the same length of time.

The transformer to carry an overload of 25 per cent. for two hours without the temperature rise exceeding 55° C.

The transformer to give full kilowatt output when operating at 90 per cent. power factor without exceeding the above temperature rise.

APPENDIX II.

Winding Specification for a Water-cooled Oil-filled 60-cycle 900-k.w. 22,700–39,300 to 2,200-volt Single-phase Transformer.

PRIMARY WINDING.

Conductor cross-section, two 0·170 in. × 0·080 in. double cotton covered.

Weight, 750 lbs. double cotton covered.

	Inside Section.		*Outside Section.*
Turns 618 in.	8 B.T. coils of 32 and 32; 2 B.T. coils of 27 and 26	...	p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_1, and p_{10}.

Winding taps made at end of 5th turn inside end of outside section p_5, p_6.

Insulation between turns (8,300 ft.) 0·015 in. thick by 3/16 in. wide, consisting of two 0·005 in. hercules parchment and one 0·005 in. mica.

Reinforced Turn Insulation.

26-turn section, last 12 turns (triple) turn insulated, and all turns 0·012 V.C.

26-turn section, all other turns (double) turn insulated, and all turns 0·012 V.C.

26-turn section, all turns (double) turn insulated, and all turns 0·012 V.C.

Coils p_1 and p_{10} special collars of 1 3/32 in. pressboard.

All wood strips to be of 3/4 in. wide by 3/16 in.

Pressboard strips to be of 1 1/4 in. wide by 3/16 in.

Taping of coils to be of 0·229 in.
Wire vacuum, 1.
Coil dimensions: bare, $7\frac{5}{16}$ in. by $\frac{1}{2}$ in.; insulated, $7\frac{3}{8}$ in. by $\frac{9}{16}$ in.
Dimensions of coils with special collars: bare, $7\frac{5}{16}$ in. by $\frac{5}{8}$ in.; insulated, $7\frac{3}{8}$ in. by $\frac{11}{16}$ in.

SECONDARY WINDING.

Conductor cross-section, four 0·300 in. × 0·115 in., two of double cotton covered and two of bare.
Weight, 370 lbs. double cotton covered and 370 lbs. bare.
60 turns in 8 S.S. coils of 15 turns each, 4 coils in series, 2 in parallel.
Insulation between turns, 1,340 ft., 0·025 in. thick by $\frac{5}{16}$ in. wide, consisting of two 0·010 in. hercules parchment and one 0·005 in. mica.
Coil dimensions: bare, $7\frac{3}{4}$ in. × $\frac{5}{16}$ in.; insulated, $7\frac{13}{16}$ in. × $\frac{3}{8}$ in.
Coils for special collars of $1\frac{3}{32}$ in.

INSULATION SPECIFICATION.

After winding the coils they must be securely clamped to dimensions called for in the winding specifications, after which they are to have the terminals attached.

Before the coils are dipped they should have a preliminary baking for 12 hours at 250° F. (120° C.), or longer if necessary, to thoroughly dry out any moisture and shellac in the turn insulation and collars. The coils should be twice dipped when hot in 0·07-B japan and baked 12 hours at 250° F. after each dipping.

After the coils have been dipped they are to receive one taping of 0·007 in. cotton tape for varnish treatment. The taping is to be put on according to directions given below.

Before putting on the taping the coils should be brushed over with a thin coat of 0·028 in. sticker to hold the tape to the coils. The taping should receive five brushings of 0·094 in. varnish of specific gravity 875, and to be baked after each brushing at least five hours, or until hard, at a temperature of 180° F. (85 to 95° C.). After each taping the coils should be allowed to cool to at least 100° F. (38° C.) before the next varnishing is given.

The taping should be put on with one-half lap, except at the corners of the coils, where it should overlap not more than one-eighth at the outside edge.

With single section coils there should be added, before the taping is put on, one thickness of No. 2 cotton drill, which is to be placed over the connecting straps. The drill should extend at least $1\frac{1}{2}$ in. each side of the strap, and must be neatly and firmly tied down with twine and sewed together at the outside edge of the coil. A tongue of the drill should extend up the outside of the strap as far as the terminal, and should be secured to the strap with a wrapping of cotton tape.

Discussion.

Mr. W. B. Woodhouse: Before I discuss the subject of the paper I just want to say one word of criticism about it: the paper contains a number of misprints and rather vague statements. For instance, on page 58 the statement is made, "The hysteresis loss varies approximately as the 1·6th power of the induction, and directly as the frequency." I presume the author means the inverse of the frequency as in a later paragraph. Then in the next one or two paragraphs I think some words are misprinted. On page 60 the author says, "It is often said that regulation reduces the voltage upon the load, and therefore causes a direct loss of revenue by reducing the power sold." This is unnecessarily vague, as is the statement on page 61 about "'all-day' efficiency." On page 64 the author refers to "dielectric flux," about which I should like a little explanation. I do not quite understand the author's meaning there. Near the bottom of page 67 the author speaks of "The dielectric density," another phrase that is new to me. On page 86, in dealing with the delta-star operation, the author says, 'It is possible under such conditions to operate and deliver 3-phase current when either one phase or one line conductor is cut out." Unless he means to use the earth as one of the conductors and operate at lower voltage I do not quite see how that can be done. The diagrams of connections are very difficult to criticise as there is no indication on them of where the feeders branch off. It would make it much easier to discuss those diagrams if those details were given. Those are all minor points. Mr. Woodhouse.

The principal point, it seems to me, in discussing transformers from the operating point of view is, first, the question of the efficiency. The author goes into the question of the relative value of two transformers of different efficiency. For water-power schemes, where the water is plentiful, the no-load losses are not so important as they are in the case of stations where coal is used. My own view is that, assuming commercial load factors, the most important losses to consider are the no-load losses. The author, in my opinion, rather underrates the importance of regulation. Pressure regulation is an important matter: first, because from the operating point of view the voltage has to be maintained within fixed limits; and, secondly, because of the question of the strength of the transformer to withstand short circuit or heavy overloads. It has been the experience of a great many of us that transformers with very close regulation are not mechanically robust enough to stand heavy momentary overloads. On the other hand, we want close regulation, and it appears with the long distances considered in this paper that we must rather submit to a transformer with poor regulation and to the use of some external means of regulating the pressure, such as the synchronous motor. I think Tables I., II., and III. would have been more valuable if the author had included the regulation of the various sizes and the no-load losses. With regard to the size of the transformer unit, it seems to me that when we get to very

Mr. Woodhouse.

big units we have to consider very seriously the question of local heating. A 3-phase transformer is more efficient and has many advantages. The only disadvantage it has is that in the case of breakdown the whole of the transformer is lost, instead of, where single-phase transformers are being used, only one-third being lost. But the single-phase transformer of one-third of the capacity has the advantage that there is not such a big bulk of metal. The difficulties of cooling equally all through the core and all through the windings are not so great, and I think that is an additional advantage which is a very strong one, particularly where very big units are concerned. The methods of cooling are dealt with by the author, but I am not clear whether he suggests that we should adopt air cooling by blowing air against the windings, or whether he means to air-cool transformers which are oil insulated. I should have thought that the practice of air cooling without oil insulation was dead. The difficulty of keeping moisture away and keeping the transformers clean and the air ducts clean is a very serious one. The self-cooled oil-insulated transformer in big sizes becomes very bulky. The amount of oil used is something of the order of 2 gallons for every kilowatt, and if it is a question of dealing with, say, a 5,000-k.w. transformer an enormous quantity of oil is required. Therefore, that is a great argument for using a special means of cooling. Water is not always available, and the alternative appears to be to blow air on the case. I think there is room for development in the arrangement of the oil in these large transformers. A very large quantity of oil has to be used for proper cooling, and some of that cooling might very well be carried on in an external tank. It has been done by some makers, but it does not appear to be general. The drying-out of transformers is a very important matter, and I was interested in reading all the particulars which the author gives of the methods he adopts. There is one very good test of whether a transformer is dry or not, and that is to measure the core losses. If the transformer core is damp the losses are increased, so that if periodical readings of the core losses when drying-out are taken it is possible to get some idea of how the transformer is going on. The comparison of the shell type of transformer and the core type of transformer seems to me necessarily inconclusive. Every maker of shell transformers says that they are better than core transformers, and the makers of core transformers state the reverse. It is all a matter of what we are prepared to pay for the transformer. From my experience I see no difficulty in obtaining a core transformer equally as good as a shell transformer. Another most interesting and important point is the question of the inter-connection of the phases on a transmission line where there is a step up and step down at the ends. The list of stations given by the author shows that there is a considerable diversity of opinion as to whether the high-voltage line should be connected delta or star. Obviously if the low-voltage side is connected star and the high-voltage side is connected delta, and loads are being dealt with which may be out of balance, the regulation is rather better

than if double-delta or double-star were employed. The balance is apparently in favour of star connections with the high-voltage line. With long transmission lines of this voltage the earthed neutral seems to me of very doubtful value. I was particularly interested during the summer, when we had such very dry weather, to notice the great increase of resistance of the earth after a few weeks of dry weather. If transmission is being carried out over several hundred miles I am afraid that earth connections would give trouble. I should very much like to hear other views on that particular point. As to the tests of the transformers, pressure tests, temperature rise, and so forth, the author apparently chooses a standard of his own. I do not know that there is any justification for departure from the recognised standard. He does not mention one test, however, which I think is of value, and that is an over-pressure test. The trouble with transformers of this kind is usually the breakdowns between turns of the winding. An over-pressure test of 30 per cent. picks out the weak spots. Mr. Woodhouse.

Dr. SILVANUS P. THOMPSON: We have to thank Mr. Taylor for bringing this paper before us, no less than Mr. Snell for the excellent digest that he has given of it. It is not every day that we get a paper from a man who has had experience of turning out in a factory transformers to the amount of 150,000 k.w. in a month, nor is it every writer of a paper who can talk about hundreds of megawatts, or about hundreds of millions of kilowatts in a short circuit. We must thank the author for the data he has given us with regard to these large transformers. Many of us have had much more experience with very small ones, and those who have had experience with these very large transformers of very high voltages are comparatively few. It would seem rather ungracious to criticise the details of a paper of this importance, and yet I venture, without becoming hypercritical, to mention two or three points where the terms used lack precision. There is one term used by the author very loosely—I do not blame him, because it is general custom to use it loosely—that I desire to draw attention to, namely, the word "regulation." I suppose we all know what we mean when we talk about the regulation of a transformer, or we think we do. There is the expression of "regulation from 1½ to 3½ per cent."—of course we know what that means; and that the change of voltage from no load to full load due to the operation of the transformer itself must not be more than 1½ or 3½ per cent. We sometimes talk about the transformer having an exceedingly good regulation or an exceedingly close regulation, which means that it hardly varies at all, that the percentage is unmeasurably small, as we would like it to be. That would be perfect regulation; that is a regulation of 0 per cent.—that is to say, no regulation at all. Take, for example, on page 60 (which I use as illustrative of the general misuse of the word) the sentence: "With non-inductive loads the regulation is nearly equal to the ohmic drop, the inductance having but little effect." This means that the irregularity, the departure from perfect regulation, is nearly equal to the irregularity due to the ohmic drop. It is like our Dr. Silvanus Thompson.

Dr. Silvanus Thompson.

old misuse of the word "efficiency" for glow lamps, when we mean the "inefficiency" of them. I think we must try to get some better understanding as to how that word is to be applied. On other pages of the paper various passages occur where the meaning is ambiguous.

The author of the paper raises several practical problems. I for one would like to know what is the present advice, given by those who have had experience on the point, of the advantage or disadvantage of the practice of putting in a resistance between the neutral point and earth line for avoiding the difficulties of a rush. It is put here as a doubtful matter, and I would like to know what the experience is.

There is a good deal said in this paper about the methods of connection when transforming from 3-phase to 2-phase. I presume the author is speaking mainly from American experience. He does not use the same language as we use in this country for such connections. When we use two transformers to work as three by teeing on, the usual way, so far as I am aware, of describing it is to call it a "Scott connection," because that method of changing from 2-phase to 3-phase was first described by Mr. Scott of the Westinghouse Company. Further, the author introduces us to something else which apparently he thinks is unknown in Europe, which he highly recommends and calls the "3-transformer 'T' method." He says, "It is used in various parts of America and for voltages as high as 33,000." I am rather surprised at this time of day to find it described as a novelty. It was publicly described in this country so far back as 1892. It is described in Professor R. Arnò's book on the measurement of differences of phase, and it certainly is used in some of the high-voltage power stations in Italy. In case there is any doubt as to what I refer to I would like to call attention to Fig. A; it looks quite different from the lower half of the top sketch given in Fig. 20, but is in reality the same.

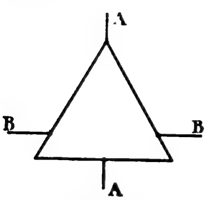


FIG. A.

Supposing we have a 3-phase delta connection, then the usual way of joining that to the three lines is by using three corners, but for the last twenty years certainly it has been known in this country that 2-phase connections can be got out of it in the following way: connect from the top to the middle of the bottom for the A circuit, and from a certain point on the side to a corresponding point at the other side for the B circuit. This is absolutely the same as the lower half of the top sketch in Fig. 20. Now we have it introduced as a novelty brought from America and called the "three-transformer 'T' method." The practical portions of this paper concerning the care in assemblage, and the switching on, and so forth, of large transformers seem to me valuable. There are various treatises on transformers in existence, but they have not generally been written by persons having an experience of the particular kinds that the author has had, and therefore the paper

should be the more valuable as a contribution to our *Journal*. Towards the end there is a remark made which I welcome—and I think our President will welcome it too—where the author says that "the experience of recent years seems to point out that the larger we build our stations, machinery, and apparatus the better results we get." I venture to think that is a piece of advice that ought to be given to those good people who, in a little congested district—such, for example, as Bethnal Green—are asking how they shall set up a little station for themselves instead of taking their supply in bulk. **Dr. Silvanus Thompson.**

Mr. C. H. MERZ: I am glad we have had this paper on transformers, because it enables questions to be raised which at the present time are very important, especially having in view the question of larger systems and larger stations. But I must say I am somewhat surprised that, with his great experience of transformers which the author evidently has, he does not refer to the more important difficulties, but seems rather to ignore them. The chief difficulty, which he hardly alludes to, is the difficulty of making a transformer that will stand the shocks that come upon it in practice without breaking down, not electrically but mechanically. The author says a good deal about the breakdown of insulation, but he does not say very much about breakdown due to the mechanical failure of the coils to stand up to their work, which is really a very serious matter. I do not believe there is any large maker of transformers at the present time who is not having very serious trouble in that connection. This is a trouble which must be got over if we are to have larger systems and larger stations, and it must be got over in some different way to that generally suggested, which is to make the regulation of the transformer much worse. If a transformer is being used merely to step up to a high voltage, to transmit electricity a long distance it perhaps does not matter so very much whether the regulation is 6 per oent. or even worse; in fact, modern practice would perhaps dictate large reactance in the generator and transformer feeding the line so as to avoid a heavy short circuit. But when we come to distribution it is obvious that if we are to have automatic regulation of voltage (and we cannot have assistants at every substation), we must have transformers of good regulation. It is impossible from a generating station to keep a constant pressure on the secondary terminals at every sub-station unless we have good regulation—regulation within 2 or 3 per cent. Therefore it is not a remedy of the difficulty of making transformers sufficiently strong mechanically, for makers to suggest that we should be content with a drop of voltage from no load to full load of 6, 7, or 8 per cent. instead of 2 or 3 per cent. There are two or three points touched upon in the paper which are very important; for instance, at the bottom of page 60, the author refers to the necessity of making a transformer so that there shall be no hot spots in it. That is certainly very important indeed, and I do not think it can be too much emphasised. If we are to avoid serious trouble with transformers, trouble with oil, and oil depositing which necessitates frequent cleaning out of the transformers, it is essential there should not be any hot spots. **Mr. Merz.**

Mr. Merz. I do not think in America they have such a high standard in this respect as we look for here. We aim at having transformers which will operate for years without requiring cleaning, whereas on some of the largest distribution systems in America I find they talk about cleaning their transformers once every six months or once a year. Then on page 61 the author refers to the possibility of operating transformers up to their limiting temperature rise. I think from the point of view of satisfactory operation this is a mistake. Unless a transformer is kept fairly cool I doubt the possibility of operating without considerable cost of maintenance on cleaning. On page 62 the author refers to the fact that water-cooled transformers originally were fitted with external oil-cooling arrangements, whereas now the modern practice is to put the cooling coils in the transformer tank. I consider this quite wrong. The original practice was to put the coils in the transformer tank; the modern practice is to put them outside.

Mr. Peck. Mr. J. S. PECK: The author has given us some valuable hints on the practical operation of transformers, especially with regard to the drying-out and the installation of the apparatus, but when it comes to questions of design, internal arrangement and connections, there are many points on which I cannot agree with him, and a few of these I shall indicate as briefly as possible. On page 58 it is stated that the hysteresis is greater in hard than in soft steels. It is now well known that alloy steels have very low hysteresis loss, yet they are usually very hard. On the same page the statement is made that "a reduction of 20 per cent. in the frequency will increase the transformer exciting current about 14 per cent." It may be 14 per cent.; it may be many times this value. It depends on the design of the transformers and how high the induction is worked. In a low-frequency transformer there would generally be a greater increase than in a high-frequency one. On the same page a formula is given for determining the cost of the iron loss. This formula is obviously wrong as the terms are incorrectly expressed. At the bottom of the page the author refers to the transformer losses as affecting the revenue. In general they will not affect the revenue except indirectly; they affect the cost of operation, and in a water-power plant their effect may be negligible. It is stated on page 59 that the copper loss "is within control of the designer." So is any other loss, within limits, if the customer will pay for it, but the section of copper cannot be increased without increasing the iron also, or without cutting down the insulation. The author further states on page 59 that "The drop in voltage due to eddy currents in the conductors, and due to magnetic leakage, is minimised by the use of several small conductors of an equivalent cross-section." Several small conductors will minimise the eddy-current loss, but they cannot reduce the magnetic leakage. It is also stated on this page, "The losses due to the magnetising current and heating are determined from the manufacturer's guarantees." I do not understand what this means. Lower down on page 60 the statement is made, "In general the core-type transformer has not so good a regulation as the shell-type." I do

not think this statement can be accepted without several qualifications. On page 61 it is stated that, "Where a transformer is operated at full load its all-day efficiency will be almost equal to its full-load efficiency." I think "almost" should be omitted. On page 64 it is stated that transformers are shipped occasionally in the tank from the factory, but that this is seldom done. As a matter of fact, the tendency is more and more to ship the transformer in its case complete with oil. The whole unit is thoroughly dried and the case sealed without the terminals, and shipped in this way, so that upon arrival all that has to be done is to put in the terminal bushes and connect to the line. Thus no drying-out is required. This is a great step in advance from all points of view, as the great danger of overheating the transformer when attempting to dry out *in situ* is entirely avoided. On pages 64 and 65 a description is given of the construction of a core-type transformer. This is probably a description of a small core-type transformer manufactured by a particular company. It is not a construction which is adopted in this country or on the Continent, and I do not think it is suitable for a large transformer. On page 67 a sketch is shown of a 3-phase shell-type transformer. The proportions given in the sketch are obviously wrong. The horizontal portion of the magnetic circuit is shown as equal to three times instead of twice that of the vertical section. On page 70 the statement is made: "Air-blast transformers are regularly built in capacities up to 4,000 k.w. and for a voltage of 33,000." I would explain that by "air-blast transformers" the author refers to those in which the air is forced directly between the coils, and through ducts in the laminations. In general, the efficiency of an air-blast transformer is not as high as that of an oil-cooled transformer, in consequence of the greater insulation space and the larger air ducts which are required; the author states the opposite. On page 72 reference is made to the testing of the water-cooling coil. One of the greatest difficulties with water-cooling coils is the tendency for any water left in them to freeze when shipped in cold weather. They are usually made in circular form, and it is extremely difficult to get all the water out after the test. If they are shipped with even a small amount of water in them and the water freezes, it is certain to burst the pipe. At the bottom of page 73 reference is made to drying out under vacuum, and a method is described where the cover is packed with putty to prevent ingress of air. In some cases a special cover is furnished which is made air-tight, and it is used first on one transformer and then on another. On page 77 reference is made to the different classes of oil used with water-cooled and self-cooling transformers, and it is stated that an oil of lower flash-point is used with water-cooled transformers, because it is easier to keep down the temperature of the water-cooled transformer. This is not the real reason for the use of a lighter grade of oil. It is found that the "water-white" oils which usually have a low "fire test" have a much less tendency to throw down a deposit when heated than have the darker fire test oils. This tendency to form a deposit is the great Mr. Peck.

Mr. Peck. trouble with transformer oils, a fact which the author has not mentioned in the specification he has given. If the deposit is formed in a self-cooled transformer, it does no particular harm, except to clog the ventilating ducts if it goes on too extensively. But in a water-cooled transformer the deposit settles on the cooling coils, and being an excellent heat insulator, the transformer becomes hotter and hotter, and the deposit thicker and thicker, until the transformer burns out, or until the cooling coils are taken out and cleaned. At the top of page 84 the author in a measure condemns the 3-phase transformer, citing the great advantages of the single-phase transformer; but a little further on he refers again to 3-phase transformers, and states that they will be the transformers of the future. On page 88 several diagrams are given of star and delta connections of transformers. Diagrams B and D are correct; diagrams A and C are impossible ones, for with the secondary winding of the middle transformer reversed, the group is short-circuited. Both the diagrams shown on page 92 are also unworkable for the same reason. On page 93 diagrams C and D are correct; while A and B are not correct, as they do not give equal voltages across the secondary phases. Regarding the so-called 3-transformer system of "T" connection, Dr. Thompson has already stated that this has been known for many years. It has not come into general use because of its many disadvantages. The principal ones perhaps are that rotary-converters or 3-wire 2-phase motors cannot be operated, and that there is no point for a mid-wire connection. But the author's whole argument in favour of this system is, I think, a fallacious one, because it is based on the assumption that there is no greater loss when operating 3-phase to 2-phase than when operating with the same output 3-phase to 3-phase. This is not the case, for the loss is considerably increased when operating 3-phase to 2-phase, and it is also greater than the loss with the Scott connection, where the same output is taken from the same total transformer capacity. On pages 99 and 101, in Appendices I. and II., a transformer specification is given. This is a manufacturer's specification, and, while it is quite interesting there are, especially in Appendix II., a number of terms which are unintelligible except to the manufacturer. In general, the first specification is one issued by a particular manufacturer, and which he would doubtless like all consulting engineers to adopt as their own.

Mr. Snell. Mr. J. F. C. SNELL: I prefaced my remarks this evening by saying that I took no responsibility for the paper, and the author must himself answer the very trenchant criticisms, of Mr. Peck in particular. I will see that the points are forwarded to him, and the author will no doubt in due course reply to the various criticisms offered. I must apologise to the Institution in one respect, namely, that some of the very obvious corrections which have been made by Mr. Woodhouse should have been made by me in going through the paper, but they escaped my notice. Although I do not take any responsibility for the paper, I did to some extent edit it. I may say in defence of the author, that the paper is the work of a practical man, who has had a great deal of

practical experience, and although I think it is interlarded with a good deal which is unnecessary, still it contains a great many points which will be of advantage to us to have recorded. Mr. Snell.

Mr. Burnand.

Mr. W. E. BURNAND: While this paper is very interesting and contains much information for which the members are grateful, when it comes to matters of detail connected with the construction of a transformer there are many points on which I disagree with the author. It is not an easy matter to alter the regulation of a transformer in the manner suggested once the core has been fixed, as a properly designed transformer has not spare room in the core for increasing the copper area. In the comparison between the shell- and the core-type of transformer, it seems that most of the points mentioned relate to the coils rather than to the particular type of transformer. Plenty of transformers of the shell type are made with the concentric style of winding, and also of the flat pancake style, and the same remark applies to the core type. In general, I believe it is considered that the pancake style is a more difficult arrangement to insulate than the concentric, which is in direct opposition to what is stated in the paper. One matter does not appear to have been touched on, and that is the cause of the breakdown between adjacent portions of extra-high-voltage systems. It seems to me that is an effect that will be understood best by considering what happens in many high-frequency experiments. It is well known that when we get up to a frequency of millions we can get, say, a few thousand volts across even an inch or so of copper with a current that would only give rise to a potential difference of, say, 1 volt at ordinary frequencies. If a transformer is switched direct on to an extra-high-voltage system there is a rush of current quite equivalent in its suddenness to what occurs in these high-frequency experiments, and the amount of that rush depends largely on the local capacity of the high-tension switchgear and connections close to the transformer, and is largely proportional to the electrostatic energy stored in these adjacent parts of the cable and switchgear. If this is the case, it follows that the shock to the end turns is practically in proportion to the square of the voltage, which explains why it is only within comparatively recent times that this has become serious, because there has been such a rapid increase in the voltages used. I should like to ask the author if he has not noticed a greater tendency to breakdown between end turns when the switch controlling the transformer has been close to it than when situated some distance off. Another point which has been referred to is the mechanical destruction of transformers on short circuit. It is recommended as a cure to increase the reactance, that means to increase the leakage field. This of course tends to limit the current that will pass on short circuit, but it must not be forgotten that this leakage field is largely the cause of the mechanical forces observed, so that although we reduce the current by increasing the reactance, we at the same time increase the force exerted by the current, and the lessening of the chance of destruction thus brought about is not quite what might be expected.

Mr. Burnand.

It is stated on page 95 as an advantage in grounding the neutral point of the star system, that a ground on one transmission line "causes a complete shut down," but I presume that is a misprint and that "disadvantage" is meant. Another point arises with regard to the 3-transformer "T" method. I do not quite see why that is called a "T" connection; it looks to me to be a delta. It will be of decided interest to hear that that system is coming into fairly extensive use in America. The advantage of being able to supply both 2- and 3-phase off four wires is a particular feature that distinguishes it from other systems. Although the 2-phase is described as symmetrical it is obviously not so from the diagrams given. That does not prevent a 2-phase motor working equally as well as it would work with an ordinary 2-phase system with one wire grounded on each phase; in

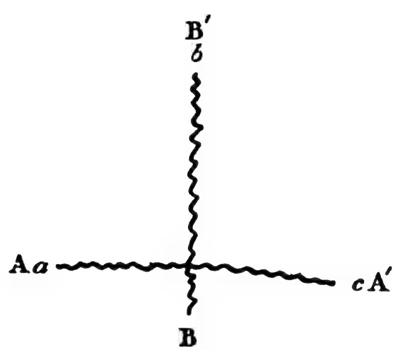


FIG. B.

fact, the 3-transformer 2-phase is rather more symmetrical than that. The chief difficulty with the unsymmetrical disposition of the phases would occur with rotary converters, but that could be overcome by means of a local auto-transformer on one phase corresponding to the vertical phase on that diagram (Fig. 20, A′ shown vertical over A), which would reduce the voltage near the top terminal and put an equal amount on the bottom. The transformer would be comparatively small and cheap and would cause very little reduction in efficiency. Appendices I. and II. have already been dealt with. They really do not tell us anything unless we know something of the remainder of the transformers to which they refer. I notice that a preliminary baking for 12 hours at 250° F. is recommended for the coils, but I suppose that is a misprint and that a much smaller value is intended. Another point is that shellac, wood, japan, and cotton drill seem to be very much insisted upon. I do not think most English engineers would care for those. Shellac dissolves in oil and, of course, wood is liable to introduce moisture and other ingredients which are not required in an extra-high-voltage transformer. Regarding the manner of supplying

approximately symmetrical both 2- and 3-phase with four wires, I should like to mention that something similar can be done by a modification of the ordinary Scott 2-transformer system by making the 86·6 tap the "T" connection. That will give just the same results on the distribution system as regards phase relations as indicated on the 3-transformer system, and I believe with a higher efficiency. Fig. B shows this arrangement. **Mr. Burnand.**

Mr. K. FAYE-HANSEN (*communicated*): Although in many points I agree with Mr. Taylor, there are quite a number of statements and generalisations from which I differ. On page 57 Mr. Taylor states that where water is not available there are only two types of transformers to choose between, either the oil-filled, self-cooled type, or the air-blast type, the latter being cooled by forced air circulation through core and coils, and he specially mentions that this type is not very reliable for high voltages. In this connection I would refer to the oil-insulated transformer cooled by means of an air blast at the outside of the tank, as described by Mr. Fleming and myself in 1908.* A fair number of these transformers have been delivered and proved entirely satisfactory, and it certainly seems to be the most suitable type for large units and high voltages where cheap water is not available for the cooling. On page 58 Mr. Taylor states that a reduction of 20 per cent. in frequency will increase the exciting current about 14 per cent. This might be the case in some special instances, but the increase in exciting current will vary within very large limits and will usually be considerably larger than given, especially for low-periodicity transformers. He also states that 10 per cent. increase in frequency reduces the iron loss by approximately 20 per cent., while the exciting current will be increased. Ordinarily the reduction in iron loss will be nearer to 10 than 20 per cent., while the exciting current will be reduced, and not increased, with increased frequency. Regarding the iron loss cost, Mr. Taylor adds the cost of energy per kilowatt-*hour* and the *annual* charge per kilowatt capacity of the station and transmission lines. It must, of course, either be the cost of energy per kilowatt-year, or the hourly charge per kilowatt capacity. As regards the copper loss cost, it is not stated what is meant by the copper loss in watts: either the average copper loss during the yearly service of the transformer, or the copper loss at full load. It seems that the formulæ given, whether the one or the other is meant, must be wrong, as the cost of copper loss should be proportional with the kilowatt-hours lost during the year, due to the actual load taking place, plus the annual charge of the increased capacity of the station required due to the copper loss at peak load. I am of opinion that the best way of figuring the cost of iron and copper loss of the transformer is based on the actual kilowatt-hours lost during the year, and the price per kilowatt-hour for the load factors, corresponding to the iron loss and copper loss, as indicated in Mr. Fleming's and my paper previously referred to. **Mr. Faye-Hansen.**

On page 60 Mr. Taylor makes the statement that in general the core-

* *Proceedings of the Institution of Electrical Engineers*, vol. 42, p. 373, 1909.

Mr. Faye-Hansen.

type transformer has not so good a regulation as the shell-type. No general statement of this kind can be justified, as it depends entirely upon the design of each individual transformer whether the shell type or the core type will have the best regulation. I entirely agree with Mr. Taylor's statement on pages 60 and 61 that it is necessary, from the point of view of reliability, to provide ducts in the windings of large-size high-voltage transformers, and his deprecation of attention being given to efficiency only and not to this feature. Mr. Taylor states that when the transformer is not operating at full load throughout the day its all-day efficiency will decrease as the load decreases. So general a statement is not true, since many transformers are designed to have a higher efficiency at low load than at full load. Referring to the tables and description of the construction of high-voltage transformers and the building of the iron core, this is only taken from the manufacture of one single firm, while other firms' transformers differ in many important features from that given. Especially the construction of the core of core-type transformers described is far from being so mechanically solid as that of the large-size core-type transformers mostly built in this country and on the Continent. Regarding the statement on page 70 that the air-blast transformer has a better efficiency than the water-cooled type of the same capacity—this can also not be taken as a general rule although it is the case with the transformers manufactured by the firm from which the tables are taken. In addition to the shell-type transformers described air-blast transformers of the core type are also built on comparatively a large scale. Personally I prefer the shell type for this service, as it is easier to arrange for separate air passages through the core and coils.

On page 71 Mr. Taylor states that if there is not more than 20° C. difference between the supply of air and the air leaving the transformer sufficient air is passing through it. This can also not be taken as a general true statement. If the transformers given in Table III. are supplied with the amount of air specified, and have the efficiency given, the air blast will leave the transformer with a rise of only 12° to 13° C. above the entering air. Under the heading "Installation of Transformers," Mr. Taylor has given very valuable information regarding the installation and drying-out of transformers. As regards the comparisons between shell type and core type on page 79, I cannot agree with the statements given there; although they may be true for certain methods of designing and building shell-type and core-type transformers, most of them are not inherent in the one or other type itself.

When Mr. Taylor comes to the description of the "T" 3-transformer arrangement I must entirely disagree with him when he states that three transformers of 33 per cent. each will give a total of 100 per cent. kilowatt capacity. In the connection shown (Fig. 20), where the windings on the 3-phase side as well as on the 2-phase side are connected in delta, it is not possible generally to say exactly how the currents will divide in the windings, as it depends upon the reactance between the primary and secondary windings and between the different parts of the windings

on the 2-phase side. From the point of view of the capacity of the transformers the best results will, of course, be obtained if either of the currents in the 3-phase windings are exactly the same, or if the currents in the 2-phase windings are exactly the same. In case the currents in the 3-phase windings are exactly the same, then the currents in the different parts of the 2-phase windings will be 0·655 and 0·765 of the current flowing in the four 2-phase leads connected to the transformer, assuming, of course, the two phases on the 2-phase side to be equally loaded. The capacity of the 2-phase transformer windings if the windings of the three are made different from each other would be 21½ per cent. greater than would be required for the same load 3-phase in delta/delta connections, and if the three transformers are made exact duplicates of each other, the size of the 2-phase windings would have to be 33 per cent. larger than in case of 3-phase transformation. The windings on the 3-phase side would, however, remain the same as for 3-phase transformation, so that the actual increase in capacity of the transformers if they are made duplicates would be 16½ per cent. larger than for delta/delta connections and 3-phase transformation. This has to be compared with approximately 7 per cent. for the Scott connection, which is the same as Mr. Taylor calls a "2-transformer 'T' connection." In case the current divides so that on the 2-phase side the currents in all the windings are the same, the required increase in capacity for the "T" 3-transformer connection would be 16 per cent. instead of 16½ per cent. as given above. In the connections advocated by Mr. Taylor the different parts of the 2-phase windings will have currents flowing in different phases, and the reactance between these different parts of the winding will have influence on the regulation of the transformer in a still higher degree than for transformers in Scott connection. It will therefore ordinarily for 2-phase to 3-phase transformation, when the conditions are such that two transformers in Scott connection are not considered to give sufficient safety, be as economical to supply two sets of transformers in Scott connection as one set in the "T" 3-transformer connection. Mr. Faye-Hansen.

On page 90 Mr. Taylor advocates the use of outside reactance to limit the short-circuit current of generators and transformers. It will usually be cheaper, and from the point of view of efficiency and reliability better, to supply the transformers with some internal reactance. In the case of transformers at the end of a long transmission line this will, of course, as a general rule not be required, since the impedance of the transmission line will limit the short-circuit current sufficiently in case of short circuits on the secondary side of the transformers. From the point of view of safety of step-up transformers in generating stations it would be advisible to connect one transformer to one generator of the same capacity with no busbars on the low-tension side, so that in case of a short circuit on the secondary side of the transformer the short-circuit current through the transformer is only supplied by generators of the same capacity as the

Mr. Faye-Hansen.

transformers, whereby the short-circuit current in the transformer is reduced to the same as that of a generator of the same capacity, while the short-circuit current of the transformer when the capacity of the generating plant behind is large enough to maintain the primary voltage under short-circuit conditions, ordinarily will be considerably higher. On page 92 Mr. Taylor advocates the use of resistance in series with the grounded circuit of the transformers to reduce the severity of short circuits to earth. I quite agree that this as a general rule would be of advantage, but would point out that Mr. Taylor in his answer to the discussion on his previous paper on "Modern Long-distance Transmission of Electrical Energy,"* says that it is bad practice to put resistance in the grounded circuit, due to the fact that the transmission line then in case of short circuits between one phase and earth, may give full voltage to earth on the two ungrounded phases. It seems, therefore, as if the advantages and disadvantages in using resistances in the neutral connection to earth about balance each other. I should like to know what actually is the usual practice in the installations Mr. Taylor has to deal with.

Professor Robertson.

Professor D. ROBERTSON (*communicated*): The calculation of the best distribution of the losses between the copper and iron of a transformer has always been a favourite academical exercise, but sufficient attention has not always been paid to the difference in the cost of peak load and light load losses. To get the least energy loss (Mr. Taylor's condition (*a*) on page 56), the transformer should have its highest efficiency for the root-mean-square load, but this does not give the least money loss, which is presumably what he had in his mind in (*b*). Every watt lost at the time of peak load adds to the capital outlay for everything up to the transformer considered (prime-mover, generator, switches, and perhaps step-up transformers, lines and sub-station gear), whereas the light-load losses only affect the running costs. The lower the load factor, the more energy can be saved by cutting down the iron loss at the expense of the copper and total losses at full load, but at the same time the capital and other standing charges become of more and more importance compared with the running costs, and in many hydro-electric systems in which storage of water has not been an expensive item the last-mentioned part of the cost must be very small indeed. The cost of each kilowatt of loss lasting for the few hours of peak load is therefore not so much less than the same loss lasting the whole day as at first sight might appear, and there must be many cases in which a saving of the peak loss at the expense of a greater all-day loss is a true economy whether the peak is a long one or a short one. Another consideration affecting the distribution of the losses is that good regulation—a commercial asset of appreciable value where other sources of power are open to the consumer—is affected by the copper loss but not by the iron loss. It will generally be found to lead to the best economy of money if the transformers be designed to give their maximum efficiency (copper and iron losses equal) at about their rated

* *Journal of the Institution of Electrical Engineers*, vol. 47, p. 167, 1911.

Professor Robertson.

full load. The real advantage of a small iron loss with a given total full-load loss lies not so much in the saving of energy itself as in the consequent lower temperature of the transformer when the peak commences.

Many of the author's statements in the paper require certain qualifications. For instance, the first one on page 58 regarding the effect of the frequency on the hysteresis loss applies when the maximum flux density is kept constant, while those appearing lower down refer to a transformer working with constant voltage. Surely some slip has been made in saying that the iron losses are reduced 20 per cent. by a 10 per cent. increase of frequency at normal voltage. Such a rise would not affect the eddy-current loss at all, and would only diminish the hysteresis loss by about 7 per cent. of its own amount, or, say, 3 per cent. of the total iron loss. The figures on this page about the effect on the exciting current can only apply to a particular case. A 10 per cent. change in the flux density, corresponding to a similar change of frequency in the opposite way, may produce anything from 5 per cent. to 100 per cent. or more change in the exciting current, according to the particular part of the magnetisation curve on which the apparatus was originally working.

Using a few very simple assumptions which are very nearly true, I have succeeded* in dividing the cost of a transformer into two factors, of which one takes account of the proportions and type of transformer and the other of the performance required. The former is called the cost function, and depends on the type, the relative proportions of the leading dimensions, and on the specific cost ratio, or ratio of the cost of the copper space to that of an equal volume of iron space, which ratio is affected by the relative cost of the copper and iron and the relative space factors in the two spaces. The other factor, the fundamental cost, depends on the efficiency required, the properties of the materials, their actual market values, and the actual space factors. The output does not affect matters directly, but only indirectly by fixing a lower limit to the efficiency for any method of cooling below which it will be impossible to make the transformer run cool enough with that output. If the iron losses varied in proportion to the square of the flux density, to get an efficiency of 98 per cent., say, would require the same size of transformer (but not the same winding) whether it was to give 1 k.w. or 1,000 k.w. The temperature rise would of course be very different, and very effective means of cooling would be required for the latter rating. Actually, owing to the departure of the iron losses from the assumed law, the transformer would have to be bigger and more expensive for the smaller output, unless larger space factors could be obtained with it. The same cause makes it always more expensive to reduce the iron loss than to diminish the copper loss, the total loss being constant.

The theory mentioned above allows very definite statements to be made as to the relative value of different types, proportions, or materials,

* Bohle and Robertson, "Transformers," p. 177. London, Chas. Griffin & Co., 1911

Professor Robertson.

which are true irrespective of size. A summary of the most important deductions may be given. We can distinguish several groups of types of transformers each of which may have either circular or rectangular coils. Some of these are: *Ring type*, having the conductors wound all round a ring of iron, which may be circular (Faraday), square (Burnand), hexagonal, etc. *Simple type*, having an iron core in the form of an open rectangle, with the coils all wound on one limb. *Shell type*, derived from the last type by dividing the magnetic circuit so that half the flux returns on each side of the coil, so as to reduce the mean length of iron. In some types, such as the Berry transformer, the coils are circular and the iron spread out radially in all directions. The division of the flux is the characteristic of the shell transformer. *Core type*, derived from the simple type by winding half of the primary and secondary on each of two opposite limbs. This division of the electric circuit is the characteristic of the core type. *Polyphase transformers* can be obtained by combining the requisite number of any of the last three types, by which a saving of material can be effected. Special types can also be made applicable to a particular number of phases. The following general conclusions apply to transformers using the same materials and having the cheapest proportions, designed to give the same losses with the same load. The smaller ones will therefore, in general, get hotter than the larger ones. (1) In all types rectangular coils are cheaper than circular; without allowing for the better iron space factor attainable with rectangular coils, the difference is about 3 per cent. for the ordinary 3-phase transformer, and 5 per cent. for core and shell transformers. (2) For single-phase transformers the ring types require least material, the circular being the best in this respect, and any other better than one with a smaller number of sides. This type offers, however, practical difficulties of construction. (3) Core and shell types cost as nearly as possible equal amounts when equal volumes of copper and iron spaces are equally expensive. (4) The core is cheaper than the shell with relatively cheap copper space (low copper space factors and alloyed iron). (5) The shell is cheaper than the core with dear copper space (large copper space factors and ordinary iron). (6) The simple type is much more expensive than any of the foregoing (50 per cent. dearer or more). (7) The ordinary three-limb 3-phase transformer is much cheaper than three single-phase transformers. In fact, for the same efficiency, to provide one spare for each group of three single-phase transformers will cost more than to entirely duplicate the 3-phase transformers. (8) The three-limb 2-phase type, being derived from the expensive simple type, is more expensive than two single-phase transformers. (9) Polyphase transformers obtained by combining two or three core or shell transformers tandem fashion (Fig. 4 in the paper is a 3-phase tandem shell transformer, but quite out of proportion), are cheaper than an equivalent number of single-phase transformers by 15 per cent. for the 2-phase and 33 per cent. for the 3-phase. (10) Symmetrical

Professor Robertson.

types of 3-phase transformers are difficult to construct, and the favourite one in which each core is divided into two parts communicating with each of the other cores makes very poor use of the material owing to the difference of phase between the fluxes in the two halves of each core.

Several of these statements are surprising and quite contrary to what one would expect. Thus (1) contradicts the usual text-book comparison of circular and rectangular coils which Mr. Taylor gives on page 59. I must confess that when going into the theory of the matter I at first dismissed rectangular coils in exactly the same way, but after reading Fleming and Faye-Hansen's paper * I was induced to tackle the problem again, taking full account of the three independent proportions, and was successful in obtaining solutions which entirely confirmed the claims made in that paper for the rectangular construction. Until an explanation of the result was forthcoming, however, my confidence in the formulæ was considerably shaken by the unexpected result. It is true that the circular coil has a lesser mean turn than a rectangular coil of the same embraced area, but the latter requires a shorter length of iron to surround it owing to its small width. When the dimensions are readjusted so as to give the same losses in each and the best proportions for each type, it is found that the latter advantage predominates and the rectangular coil is the better. The very great saving which the core and shell constructions give as compared with the simple type from which they are derived is also hard to believe. The first saving by reducing the copper or iron length is only a few per cent., but the losses are reduced at the same time and consequently all the dimensions can be reduced until the losses are the same as before, with the result that what appears at first to be only a small gain becomes in reality a very large one. It is curious to note that the cheaper of the two (core and shell) is the one whose initial saving is in the less expensive space, another result contrary to what one might expect. It is a mistake to say that any type is in itself more efficient than another, as an efficiency of as near 100 per cent. as may be required can be obtained by making it big enough. It is all a matter of money, and some types cost less money than others to get it. Naturally, the smaller transformers will get hotter than the larger ones with the same load and losses, and consequently the minimum efficiency for a given load is higher for the cheaper types than the dearer ones, and so part of the saving in cost for equal efficiencies has to be spent in getting a higher efficiency when, as is usual, the rated output is settled by the temperature rise. For instance, the same efficiency can be obtained by a 3-phase transformer or by three separate transformers for the same service, but if the former is working at its limiting temperature, the latter will have a considerable margin, and could be rated higher. The result is that the man who prefers separate transformers is generally content to sacrifice his efficiency below that obtained by his fellow who employs 3-phase units, in

* *Journal of the Institution of Electrical Engineers*, vol. 42, p. 373, 1909.

Professor Robertson.

order that his capital expenditure may not compare so very unfavourably with that of the latter as it otherwise would. On an equal heating basis, single-phase transformers do not appear quite so badly as is given in (7) above. Taking Mr. Taylor's figures on page 84, which presumably refer to ratings for equal temperature rise, the relative cost of two 3-phase and four single-phase ones, any three of which are equivalent to one of the former, rises from something under unity for equal efficiency to about 5 : 4. The efficiencies given in the author's Tables I. and II. (pages 62 and 63) are certainly not high for the output; in fact, it is only the use of water cooling which enables those for the smaller sizes to be kept so low. I wonder whether in the smaller sizes it would not actually be cheaper to have a greater efficiency and dispense with the water cooling. Near the limits of any particular method of cooling it is always well to consider whether it is not better to spend the money in raising the efficiency sufficiently to allow of the simpler method rather than in providing more expensive cooling facilities.

The author's comparisons of core and shell transformers on page 79 are hardly quite fair to the former, because they are really a comparison of concentric and sandwiched coils, which is quite a different matter. Although, perhaps, the latter are the only ones suitable for shell transformers, either may be, and both are, employed for core transformers, most makers, however, preferring the concentric type. In the shell type with its short, thick winding space, a large amount of subdivision is necessary in order to get a reasonably low leakage reactance, whereas with the long, thin winding space of the core type simple concentric coils generally give a sufficiently good result. It is, of course, easier to get a small improvement with sandwiched coils by increasing the number of sections, and so there is no difficulty in making the ordinary shell as good as, or even a little better, than the ordinary core. But with the same amount of interleaving the core ought to be the better. It is not the case that the shell transformer is essentially the better cooled. Without any ducting, the shell has only about half the copper cooling surface of the corresponding core transformer, but about 50 per cent. more iron surface. As there is no reason why the same amount of subdivision should not be carried out on both types, this ratio should also approximately apply after ducts have been inserted, and so the core type would seem to have the advantage as it has the cooling surface where it is most wanted. Of course, sandwiched coils give a greater increase of cooling surface than concentric ones.

Near the bottom of page 86 the author refers to the transmission of 3-phase power with one line cut out. As at least three conductors are absolutely necessary for the purpose, it may be assumed that he contemplates using the earth as the third. Is this actually the practice in America, and do the telegraph and telephone authorities offer no objections? The statement at the bottom of this page appears to contradict the one given a few lines above it.

Mr. C. J. Hopkins (*communicated*): The author refers with emphasis to the reliability of transformers as an important requirement, which is, of course, dependent upon a skilful design and construction. Mr. Snell, in reading the paper, laid special stress on the fact that this paper referred to transformers between 33,000 and 110,000 volts and upwards, which is according to the text. I object to the words "and upwards." Fig. 3 shows a picture of a transformer and depicts quite clearly the usual method of carrying the high-tension leads through the cover, as stated in Appendix I., that they are to be carefully insulated and taken from the tank through porcelain bushings having sufficient surface to prevent perceptible leakage to the tank. With voltages above 110,000, on account of the difficulty in preventing leakage, the above method of taking these high-tension leads through the cover with simple insulation and a porcelain bushing becomes more or less impracticable. About seven years ago I took part in the design of some 250,000-volt transformers in Schenectady; these were, as far as I know, the first to be constructed at such a high voltage. In these designs the matter which demanded the most attention was the method of satisfactorily taking the high-tension leads through the cover. This was accomplished by supporting the leads (bare copper rods) in the centres of cylinders of oil, which were in turn supported at a point near their centre in the cover of the tank. These cylinders were built up of cylindrical sections of varnished cambric and pressboard collars; illustrations are given in the manufacturer's bulletins. Mr. Taylor also mentions that these high-tension transformers are usually required to be tested to twice their working voltage. Would it not be unnecessarily extravagant to demand that a transformer that is to be built for 250,000 volts must be capable of withstanding 500,000 volts? **Mr. Hopkins.**

The President: I will now ask you to accord a hearty vote of thanks to the author for his interesting paper. **The President.**

The resolution of thanks was carried by acclamation.

Discussion before the Birmingham Local Section on November 15, 1911.

Dr. D. K. Morris: I should like to point out that in the interesting comparison of the core and shell type of transformers, given by the author on pages 79 and 80 of his paper, the advantages are mostly in favour of the shell type and the disadvantages stand in favour of the core type for the most part. Somehow the chief points in favour of the core type, viz., the ease in assembling and simpler insulation (occupying less space and so making for better regulation and efficiency of the core type) were not mentioned in this part of the paper, although they were all stated on page 67. I suggest that it would be more convenient if all these points were brought together in the paper. **Dr. Morris.**

Dr. Garrard. Dr. C. C. GARRARD: This paper, while containing very much valuable information, loses much of its value by the involved manner in which it is presented and by being interlarded with a large number of what may be described as platitudes, such as on page 61, "the efficiency of a transformer is the ratio of the output to the input," etc., and on page 71, "the transformer tanks must be made of a metallic or non-combustible material." The most valuable part of the paper is that which deals with the installation of transformers, drying out, etc. The operating engineer will find many very useful hints here. The table which is given showing time taken to dry out transformers is especially good. I have to disagree with the author in several of the constructional details he mentions. For example, describing the building up of the core of a core-type transformer (page 65), he describes the core as only being held together with linen tape. This is an unsatisfactory method of construction. The tape is bound in time to give way, and then there is nothing to prevent the laminations bulging out and cutting through the insulation of the coils. To make a satisfactory mechanical job steel bolts should be put right through the laminations, with gun-metal clamping plates in either side. The ends of the bolts are riveted over, and if they with the plates are insulated from the core, no appreciable increased iron loss results. I also have to object to the insulation specification given in Appendix II. The instructions are to put on various coats of "sticker" and varnish so many mils thick. I do not know whether the winder has to measure the thickness of varnish he put on with a micrometer. Such an instruction is impracticable. The chief objection I have to the specification is that no mention is made of vacuum treatment. I am of opinion that the coils of all high-voltage transformers should be dried and impregnated by a vacuum process.

The author deals with the old controversy of shell-type construction *versus* core-type. I think this is greatly a war of words. Equally good results can be obtained with either form of construction. There is no fundamental advantage in the one type; it is simply a question of how the design is worked out. I prefer the core type owing to its greater simplicity and the ease with which repairs can be carried out. On page 64 the author speaks of the yokes as being of the same cross-section as the cores. It is true there is the same flux in both, nevertheless it is often more economical to reduce the cross-section of the core and increase that of the yoke, owing to a shorter mean turn being thereby secured. This was worked out very fully by a writer in the *Elektrotechnische Zeitschrift* some time ago. Also it often pays to make the shape of the coils of core-type transformers elliptical rather than round, as mentioned by the author, as this results in a general saving in weight and thus in reduced material cost.

I am sorry that the author has not been able to deal with the question of the breakdown of transformers between the turns nearest the terminal when switching on. There has been considerable discussion as to whether this can best be avoided by the use of exterior choke

coils or by reinforcing the insulation between the terminal layers and turns. I am in favour of the latter course with transformers, as I hold they should be complete self-contained units strong enough to withstand the ordinary usage to which they are subjected. With regard to the various schemes of connections given, there appears to be a mistake in Fig. 12 (A), as all three of the secondary terminals are taken off one point. As regards the system of star-delta connections shown in Fig. 12, the star being on the primary side, this leads to inferior regulation on unbalanced loads. This is easily seen if we consider one leg of the secondary delta as being loaded alone, the other two legs being not loaded. Then the corresponding primary current has to be given by two of the legs of the star; that is to say, the current in one of the legs will be out of phase with the voltage and give the same regulation as if the secondary current were out of phase considerably more than it actually is. The star-delta connection with the delta on the primary side is a very good one when lighting and power current are both required to be taken from the same transformer. The motors are supplied from the three phases and the lighting from phase to neutral. With this system the regulation is not affected by unbalanced load. The author does well to draw attention to the need of paying particular attention to the connections if parallel running is to be obtained with 3-phase transformers. The necessity of this is not always appreciated. Thus two 3-phase transformers may be connected in parallel on the low-tension side, and yet it may at the same time be impossible to connect them in parallel on the high-tension side. The author's recommendation always to use the same method of connections is very much to be recommended. I do not understand the system of protection adopted in Fig. 14. Presumably the two power transformers are similar. I therefore think they should both be protected in a similar manner. It seems illogical to protect the one with a reverse-current relay and the other one with one of the overload type. As regards the "T" connection for the transformation of 3-phase to 2-phase current, this in the 2-transformer method is really the Scott connection. The 3-transformer method is new to me. I should like to inquire how it compares in regulation and balancing with the 2-transformer method. The author states that there is an improvement; does this also refer to unbalanced loading? Dr. Garrard.

Mr. R. ORSETTICH: It is extremely difficult to criticise at short notice a paper like Mr. Taylor's, the subject matter of which extends from the principles of design down to the details of construction of the most difficult transformers yet built, viz., those for voltages of 100,000. The troubles usually to be experienced with all high-tension transformers could be classed under three headings. (1) Trouble with the terminals, due to short circuits or surges, which sometimes crack the porcelain. These have been obviated in extra-high-tension sets by the use of the condenser type terminal, consisting of a number of concentric tubes, which divide up the strain of the material between the several layers. (2) Moving of coils under the strain put on them in Mr. Orsettich

Mr. Orsettich.

switching on and off heavy loads. This is obviated in all the modern types by tightly clamping the core itself, and independently from it the coils, so that no movement or vibration is possible either in the portion of the winding embedded in the core or in the parts projecting from it. Any movement of the coils, of course, means sooner or latter a breakdown of the insulation. (3) Piercing of the insulation between adjacent turns due to surges. This is being obviated by making the insulation on the turns of the first coil of the primary connected to the terminals much heavier than on any other coils. A direct test of this increased insulation is not possible, but it is obtained indirectly by putting a pressure equal to double the working pressure between this coil and the remaining coils of the same winding, or between this coil and the frame.

Two other points do not appear to have been mentioned in the paper—viz., the ageing of iron, and the employment of special alloys like "stalloy." The controversial question of air-cooled against oil-cooled transformers has been settled in practice in favour of the oil-cooled ones, and the number of these which are being installed every day is far in excess of the other type. I have no doubt, however, that it was not only the question of the cooling that settled the matter in favour of the oil, but the question of the additional safety due to the presence of the oil round the windings, and the fact that the exclusion of air meant at the same time exclusion of dust and dirt. With regard to the special connections required for a "T" system of transformers mentioned in the paper, one considerable objection seems to me to be the number of terminals required on each transformer. These on very high-tension transformers would represent a considerable weakness of the design, since they increase the chances of breakdowns, also the cost of the transformer very considerably. Tappings and extra terminals are easily made on transformers of moderate voltages, say up to 10,000 volts, but become a very serious matter for higher voltages, where simple internal connections are essential for safe operation.

Three specifications are given at the end of the paper, but it is not very clear for what purpose. The first two apparently should be consulting engineers' specifications, the last one a manufacturer's specification. The first two, however, are of very doubtful usefulness, as they take the trouble to specify high-permeability iron and low losses without giving any limit or loss factor, and, on the other hand, omit to specify such items as efficiency and regulation, dielectric test for the oil, temperature of the water available for cooling the oil, or the method of supporting, lifting, and moving the tank (truck). In the manufacturing specification the thickness of the coating of varnish is specified to three decimals of an inch, while the vacuum impregnating oven is ignored, and the cause of the hardening of varnish is entirely misunderstood, being put down to heating, whereas it is due to an oxidising process.

Mr. A. M. Taylor.

Mr. A. M. TAYLOR: The author's paper is written from the point of

Mr. A. M. Taylor.

view of South American experience, where very high voltages are the rule and frequent breakdowns apparently not the exception. The voltages being so high, transformer breakdowns are much more frequent than in this country. Hence there is probably much point in the author's strong preference for delta connection of the primary of step-down transformers; in that the open delta could be resorted to in case of a breakdown, thus dispensing with the broken-down transformer. For similar reasons the author preferred single-phase to 3-phase transformers, the reason being that it is not possible so easily to get rid of the broken-down limb with the latter, whilst a single-phase transformer can easily be removed from the circuit.

These breakdowns with 3-phase transformers are not at all so frequent in Great Britain, as the voltages are so much lower. Three-phase transformers also appear to be favoured on the Continent. In a comparatively recent installation at the Löntsch station, in Switzerland, Messrs. Brown, Boveri & Co. have installed 3-phase transformers for a 48,500-volt transmission. These transformers are each of 5,250-k.v.a. capacity for 50 periods. They are water cooled, and therefore comparable with those given in Mr. Taylor's Table III.

Some English transformers of 1,700-k.v.a. capacity 25 periods and oil-cooled, might be compared with the air-cooled transformers in Mr. Taylor's paper. These English transformers have now been running most successfully for three years in one of the largest English stations. In comparing the English and Continental transformers with the 4,000-k.w. transformers in Mr. Taylor's Table III., unfortunately Mr. Taylor has omitted to give any clue as to whether his table referred to 3-phase or single-phase transformers. Perhaps he will make good the omission in his reply. The figures are given below and on page 126.

If Mr. Taylor's Table III. referred to single-phase transformers the kilowatts per square foot would, no doubt, have come out much lower than the figures given above. In the case of the 1,700-k.v.a. transformers he knew that the floor space was a very important consideration, and where sub-stations have to be placed in the hearts of big towns it would be of much more importance than it naturally could

1,700-k.v.a. Air-cooled Transformer.

(Dimensions, 86 in. × 25 in. × 98 in. high.)

Kilowatts per square foot	55
Kilowatts per cubic foot	6·7
Gallons of oil	640
Gallons per kilowatt ...	0·376
Cubic feet of air per minute...	7,500
Periodicity	25

4,000-k.w. (Table III.) Air-cooled.

(Dimensions, 90 in. × 74 in. × 137 in. high.)

Kilowatts per square foot	86·5
Kilowatts per cubic foot	7·6
Cubic feet of air per minute	6,750
Periodicity	25

Mr. A. M. Taylor.

400-k.w. (Table III.) Water-cooled.

(Dimensions, 107 in. × 63 in. × 150 in. high.)

Kilowatts per square foot	86
Kilowatts per cubic foot	6·85
Gallons of oil	1,950
Gallons per kilowatt ...	0·49
Periodicity	25

5,250-k.v.a. (Brown-Boveri) Water-cooled.

(Dimensions, 82 in. × 59 in. × 136 in. high.)

Kilowatts per square foot	162
Kilowatts per cubic foot	14·2
Gallons of oil	1,130
Gallons per kilowatt ...	0·215
Periodicity	50
Full-load efficiency ...	98·95
Half-load efficiency ...	98·85
Voltage drop (P. F. = 1)	0·62%
Voltage drop (P. F. = 0·8)	3·0%

be in South America. I think, therefore, that taking into consideration the lowness of pressures in this country, and the consequent ease of designing transformers to stand these pressures, we are warranted in installing 3-phase transformers in most cases.

As to the "T" 3-transformer method, I have not had time to consider this; but it seems a good feature to be able to change to the Scott system if one transformer broke down. The author did not show how he obtained the 2-phase current with open delta, or what advantage the latter had over the Scott system. Perhaps he will supply this information.

THE MECHANICAL DESIGN OF DIRECT-CURRENT TURBO-GENERATORS.

By R. J. ROBERTS, Associate Member.

(*Paper received October* 6, 1911; *and read before the* MANCHESTER LOCAL SECTION *on November* 7, 1911.)

SUMMARY.

The latest type of electrical machine is the high-speed or turbo-generator. The alternating-current turbo-generator is now manufactured by several of our largest manufacturers in standard lines; but these took several years of enquiry and experience before they arrived at their present excellence of design. The difficulties or deficiencies in knowledge were both electrical and mechanical, and as the problems involved were simpler than those of the direct-current turbo-generator, their construction was first understood. Although the first turbo-generator built was a direct-current one, progress with these machines has not been as great as might have been expected.

Much has been written upon the electrical design, but still much experimenting and investigation is needed before our knowledge in this direction can be called sufficient. The mechanical difficulties are also great and just as important of solution, and it is the author's object to show some of these difficulties and generally to consider their solution.

Common Defects.

The most common defects are found in the collecting gear, and take the form of sparking, which is not necessarily an electrical defect, and may arise from—

(*a*) Unsuitable brush-gear or collectors.
(*b*) Want of balance generally.
(*c*) Unstable construction of commutator.

(*a*) May be caused by the transmission of vibration from other parts of the machine, from insufficient or too much pressure on the brushes, or even from an unsuitable brush-holder that permits the brushes to rock.

(*b*) This is possibly caused from movement of some part of the rotor after original balancing, or even during a run. Further, it may be due to insufficient care having been originally taken in balancing each unit of rotor before assembling, which possibly may mean an excentric displacement of the commutator surface to obtain good balance. Lastly, a possible cause of this trouble is the critical speed being too near the running speed, but this is very seldom seen in recent machines.

(*c*) By unstable construction of commutator is meant insufficient strength to hold together when running, or to remain true to its original axis of revolution after a period of running. This is seen by the rising of the insulating mica segments between bars, and may be due to defective mica, or to the movement of one or more of the shrink rings; or even to the failure of the support of the commutator bars, necessarily of some insulation, to stand the various expansion strains or the grinding action of flexure of the shaft relative to commutator.

Another common defect is found in the insulation. It is noticed that all high-speed machines, especially with forced ventilation, rapidly accumulate dirt or soot; and frequently it accumulates where it is impossible to clean, either by blowing or brushing. On direct-current machines it is impossible to do without exposed conductors, and this dirt accumulates and possibly bridges the creepage surface from conductor to earth, or from conductor to conductor. Again, the insulation, although of ample dielectric strength, may not be strong enough to stand the mechanical stresses put upon it.

The bands are another frequent source of trouble, and this trouble is the most disastrous of all. The bands over the armature end windings, whether of wire, forgings, or castings, sometimes break, which, of course, means a wrecked machine.

A broken or bent shaft seldom occurs excepting after a burst.

Practically the only defect in the stator is in the insulation, as the forces acting upon the stator conductors, due to a short circuit, are not so great as are found in the alternating-current turbo generator.

Stator or Field Magnet.

The design and construction of this part is one of the simplest details of this class of machine.

Broadly speaking, there are two types of stators commonly used, viz., those with laminated, and those with solid or cast yokes. These may be subdivided into three groups by the styles of windings used, viz., the distributed or Deri compensating winding, the interpole compensating device, and the use of interpoles and distributed compensating windings. The latter combination generally finds most favour in this country with solid cast magnet system, and laminated pole-shoes which carry the compensating windings in slots punched in them.

The whole design of carcase must, of course, conform to the scheme of ventilation used. The windings should be arranged so that the cooling air may have ready access to all conductors, and yet leave no pockets for hot air. Further, ample clearances must be given for the winder to do his work well and neatly, which are, of course, matters of judgment and experience. All conductors must be clamped so as not to leave more than a 10-in. length unsupported.

Ventilation.

Forced ventilation of some sort is necessary with turbo-generators because of the large loss occurring in a small bulk; and owing to the high peripheral speeds employed, total enclosing of the machine greatly reduces the noise caused by the high air velocities.

The radial ventilating ducts in the rotor core must not be placed directly opposite similar ducts in the pole-faces, as whistling or shrieking is the inevitable result.

The ventilating scheme usually met with entails the entrance of air at the back end (away from commutator) by means of fans affixed to rotor at that end. Part of the stream of air goes direct to the stator and thence out through the top outlet; whilst the greater part goes through into the rotor by axial ducts in core along the shaft. Part of this stream goes out through the radial ducts in rotor and stator and thence out; whilst another is drawn through the rotor core right to the commutator, whence it is driven by some fan up to the stator end windings and so out through the top outlet (see Fig. 1).

The greater bulk of loss in a turbo-generator is generated in the rotor, and too much fan, although increasing the total quantity of air driven through machine, increases the losses and provides more heat to be dissipated; and the aim of the mechanical designer should be to get the greatest quantity of air through that part producing greatest loss, with the expenditure of least power.

With large alternating-current turbo-generators it is now common practice, not only to employ forced ventilation, but also to clean and scrub the air before it is introduced to the machine. With direct-current machines these precautions are not so necessary because of

the lower generating voltage; but it is not advisable to use the engine-room atmosphere for ventilating purposes, as it contains so much steam and oil in suspension. In some parts of England the outside air is not any cleaner than the engine-room atmosphere, and in time it coats the machine with a highly dangerous deposit of greasy soot. If it were possible to build a direct-current generator without any exposed conductors this dirt would not be so dangerous; but unfortunately this is not possible. Then the creepage surface from exposed conductor to earth must be as large as that which experience indicates, or it must be formed so that it may be kept clean by the streams of air passing over it.

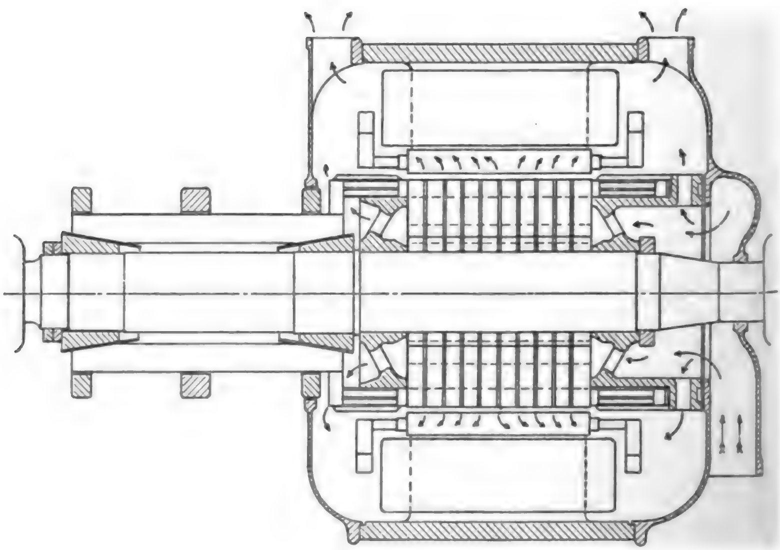


FIG. 1.

It is now usual to find dust screens fitted in the air ducts to turbo-generators. Although these are to a certain extent expensive and troublesome, they are perhaps the simplest and cheapest remedy we have for keeping the machine clean. It has been suggested to make the machines simply totally enclosed, and to cool them either with a water jacket or with a carbon dioxide or ammonia freezing plant. These schemes are more complicated and costly, as a rule, than any dust screen would be, and certainly more dangerous.

To cool large transformers it is usual to pass the transformer oil through a cooling system of water pipes. Then it appears practicable to pass the cooling air of a generator through a similar system, which might conveniently be placed under the generator, and so use the same air over and over again without it being contaminated with external

air. A leaky or burst water pipe would then be of little consequence, unless the velocity of air in cooler was sufficient to carry drops of water into the generator. This scheme, however, would generally be more expensive, though less troublesome, than a dust screen, but is particularly adaptable for a separately driven fan.

The quantity of air generally used for cooling purposes is 80 to 100 cub. ft. per minute per kilowatt loss; and, of course, where the commutator is separately cooled the commutator losses are excluded. The power required for fans and air friction is generally a large proportion of the total loss.

With certain assumptions the following table gives customary fan losses for various sizes of machines with a scheme of ventilation as shown in Fig. 1:—

Total Output, Kilowatts.	Kilowatt loss, per Cent.	Loss, Kilowatts.	Cubic Feet Air, per Minute.	Power required by Fan, in Kilowatts.	Fan Loss, per Cent.
100	10·0	10·00	1,000	4·0	4·00
150	9·0	13·50	1,350	5·4	3·60
200	8·0	16·00	1,600	6·4	3·20
250	7·5	18·75	1,875	7·5	3·00
300	7·0	21·00	2,100	8·4	2·80
400	6·7	26·80	2,680	10·7	2·68
500	6·4	32·00	3,200	12·8	2·56
750	6·0	45·00	4,500	18·0	2·40

One k.w. per 100 cub. ft. of dry air per minute will raise the temperature of air 30° F. The improvement gained by having the supply of air at a lower temperature than that of the engine-room is easily noticed. The difference in temperature of the outside air and that of an engine-room is frequently from 20° F. to 60° F.

An improvement in fan loss might possibly be secured by doing away with radial ventilating ducts in rotor and merely using axial ducts as shown in Fig. 2. The adoption of this or a similar scheme would mean a reduction in fan loss of 1 to 1½ per cent. Further, a still greater reduction might be obtained by discarding inefficient fans on rotor and using a more efficient separately driven fan.

Shaft.

In the early days of the manufacture of these machines the critical speed of the shaft was often a thing little understood. Nowadays, however, so much has it been investigated and written upon that its accurate calculation no longer offers any great difficulties. There is, however, one uncertainty, which is offered by the necessary factor to be allowed for a rigid or self-aligning bearing. It is the author's experience that, excepting where a shaft is continuous, all

bearings should be treated as self-aligning. The reason for this is that the running clearance in a forced lubrication bearing is generally so large as to prevent the bearing having any influence upon the critical speed of the shaft. Further, the erector's fear of a heated bearing frequently induces him to scrape the bearings before erection; in fact, he will sometimes scrape them for each erection irrespective of whether they have been scraped before. The author knew of a machine with rigid bearings that ran well with at least 10 mils clearance all round the shaft, and a want of truth of circularity of bearing bush of at least 5 mils.

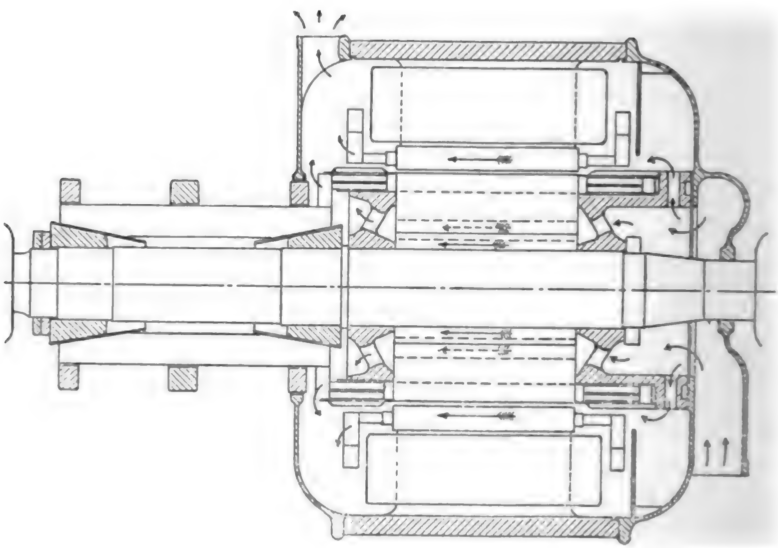


FIG. 2.

The absolute circularity of the shaft in journal calls for particular care if good balance is to be attained.

A well forged axle steel shaft is generally good enough for this class of machine. The weakest place is usually in the journal, and it is the size of journal that fixes the quality of steel, which is also fixed by whether the generator runs above or below its first critical speed. The ultimate strength should be from 35 to 40 tons per square inch, and the elastic limit 25 to 30 tons per square inch. The carbon should be 0·4 per cent., and sulphur and phosphorus less than 0·035 per cent. each. Owing to the tendency of long shafts to warp during turning it is desirable to anneal them carefully before the finishing cuts and grinding are attempted.

The stresses that may occur in a revolving shaft are generally incalculable, because it all depends upon the method of balancing

used, and upon the skill of the balancer, who generally has an inclination to force it through the critical speed in order to get clearer markings for the out-of-balance points. The author has known a shaft to vibrate under these conditions to ten times its static deflection, thereby producing a stress of over 20,000 lbs. per square inch.

BALANCING.

The whole art of balancing can only be learnt and not taught. There are laws, but these can only be found out and applied properly by the balancer himself who may reason them out or stumble against them. The essential attribute of a balancer is patience, without which he will be tempted to rush his machine through the critical speed before the quality of balance warrants it. Excessive vibration may not only damage the shaft, but it may also damage other parts of the rotor, notably the supports of the commutator.

The balance weights should preferably all be of the same mass and affixed at the same radius, or where this is not practicable they should be of a mass inversely proportional to their radii of gyration.

For the purpose of balancing, the author prefers very rigidly fixed bearings with ample clearances round the shaft to any form of spring controlled or sliding bearings, as these latter have an unfortunate habit of setting up vibrations of their own which may seriously affect the positions of balance markings.

Before assembling the rotor, the different parts should be separately balanced by themselves; but too much care in this is frequently thrown away, as the rotor windings are often irregular and have a greater influence upon the balance than other parts of rotor.

ROTOR CORE.

This is always of stampings, and in complete circles. Neglecting tooth stresses, the stresses occurring in these discs are similar to those occurring in disc flywheels, and are capable of similar treatment. The maximum stress is always at the centre next to the shaft, and if this stress is appreciable there will be a tendency for the whole core to be loose at full speed.

To see if this looseness would be noticeable a typical case is given of a core 22½ in. outside diameter, and 9 in. inside diameter, 22½ in. long, running at 3,000 revs. per minute.

The maximum stress at inner periphery is 12,600 lbs. per square inch, which gives a strain of 0·0038 in. on the diameter. The increase in diameter of a 9-in. shaft is 0·000095 in., and is here negligible.

The weight of core is 2,200 lbs., and the possible change in position of centre of gravity is 0·0038 in. This would be equivalent to 0·75 lb. at periphery, which is more than sufficient to upset the balance.

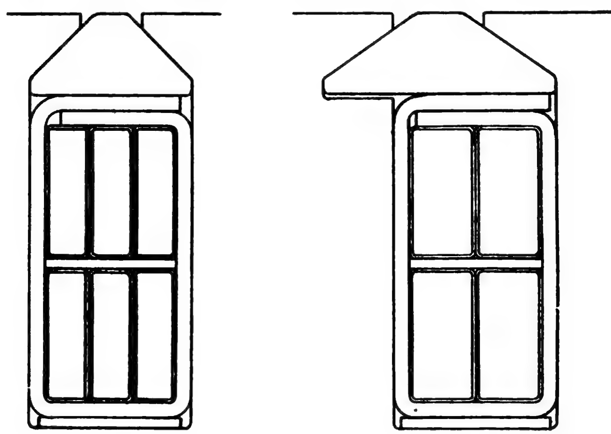
The core should therefore be so fixed to shaft that it cannot become loose. Shrinking the plates on the shaft may increase the core losses, and stampings cannot satisfactorily be pressed on. However, this may

be overcome by suitably designing the shaft and core so that the diametrical strains of shaft and core are equal.

It has been proposed to build the stampings upon a sort of cylinder, fluted axially on both inside and outside peripheries, that may afterwards be pressed upon the shaft with sufficient straining to prevent the core ever becoming loose relative to the shaft. This at first sight appears a good solution of the problem, but care must be used in the design of this cylinder lest the core should have a natural frequency relative to the shaft of somewhere within the speed of rotation. The result of anything like this, though unlikely to happen, would have more disastrous effects than the one we are trying to overcome.

Rotor Slots and Wedges.

Slotted cores are now almost universely adopted. The shape and size of the slots are, of course, settled by electrical considerations, and



a. *b.*

Fig. 3.

may contain two, four, or six conductors per slot. They have sometimes been made with closed openings ; but difficulties in reducing the reactance voltage per segment of commutator has resulted in the adoption of open slots, the armature conductors being retained in place by means of wedges driven into recesses in the teeth.

The use of wooden or fibre wedges in slots is most general ; but with the higher peripheral speeds this means a great depth of wedge, which can be accounted some loss of utilisation of material. To reduce this depth of wedge it is customary to half-close the slots and thus reduce the span of wedge. With two bars per slot, each bar is usually divided into three separate ones in parallel, which not only reduces the eddy-current loss in conductors, but also enables the bars to be put into slots with narrow openings. The middle bar is dropped in last between the other two. With four bars per slot the slot opening is

often placed to one side, so that the bars can be dropped in one by one, and yet leave the slot opening about one half the slot width (see Fig. 3).

Sometimes metal wedges insulated from the core are used, and perhaps this is a step in the right direction; but not only are they difficult to drive into place, but the eddy currents induced in them must mean some increase in total rotor loss. What is needed is a hard, tough insulating non-hygroscopic material that can be machined to fit slots. A solution may be found in the use of wedges formed of a combination of metal and insulating fibre after the manner of reinforced concrete.

Rotor Winding.

The rotor end connections are usually of the ordinary diamond or barrel type tightly packed together on top of the winding drums. Each separate conductor must be well taped and insulated from its neighbour, and a substantial band of insulation must be put between the top and bottom layers. This insulation should be selected more for mechanical than for dielectric strength and should be able to take up any small strain without tearing or buckling. The same remarks apply to the insulation used on top of winding supports, and under the bands or retaining rings. Some prefer micanite, which, when soft, can be moulded to a certain extent, and so is capable of taking a new shape without cracking or buckling. Others use a combination of leatheroid and micanite, the leatheroid being in overlapping segments and giving the necessary mechanical strength whilst the micanite gives the dielectric strength.

At the back end of the armature there is no need for any exposed connections, and so the winding can be finished off and leave no exposed part of the current-carrying system. At the commutator end, however, this is not attainable because of the large number of commutator risers which are of necessity exposed; and this place is the weakest of all for insulating purposes. It is generally necessary for cooling purposes to have air flowing axially through the core and risers. Where the conductors leave the support of the winding drum, there is a high velocity current of air which will deposit dirt rapidly into any corner or eddy. The result to be obtained here is not only a sufficient creepage surface, but the elimination of all corners or ledges where dirt might collect.

Series armature windings are seldom used because of the high current value per conductor. Equalising connections are used for the following reasons:—

(*a*) No absolute reliance can be placed upon the axis of rotation coinciding with the axis of shaft.

(*b*) It is well known that whereas the shaft remains bent to the line of deflection before the first critical speed is reached, it afterwards becomes straight, thereby raising the rotor.

(*c*) During the setting of armature in field the armature is necessarily stationary, and when running the pressure of the oil in bearings raises the shaft off the journal,

Thus it is seen that equalisers are absolutely necessary with a field of more than two poles. They must be well insulated, and should not show the bare conductor, upon which dirt may collect. They must be very rigidly fixed and supported, lest they should move and so cause unstable balance and harm to the insulation. Sometimes they are built in as part of the commutator, and sometimes arranged under the commutator end winding with connections taken to the commutator risers. The best position, to the author's mind, is at the back end under the band. The equalisers are made of complete rings of copper with projecting tags that are sweated on to the armature conductors. The whole (Fig. 4) is first firmly packed up with insulating strips of

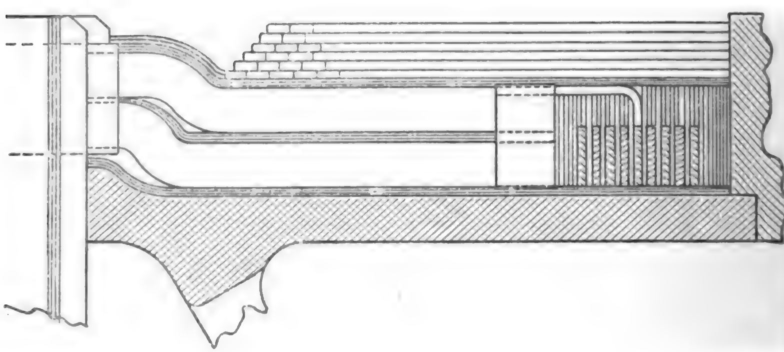


Fig. 4.

presspahn or fibre and then banded, which holds everything absolutely rigid and well covered up.

Rotor End-plates.

The rotor end-plates and winding supports should be of some non-magnetic material, to reduce eddy currents set up by the field around the armature conductors. They should be shrunk on to the shaft, the same argument applying here as for the armature core.

Banding or End-winding Sheaths.

There are many different opinions as to the relative merit of employing wire bands or solid metal rings for taking the centrifugal forces of the end armature winding. Here the problem is slightly different from that of the alternating-current turbo-generator, as the winding is symmetrical, whereas in the alternating-current generator rotor it seldom is.

The advantages of a solid sheath are not many, and beyond being able to retain its shape more easily under an inequality of loading, and being in one piece and looking more like an engineering job, there is little to be said in its favour.

Its defects are many. First, it must be shrunk on, and once on it is not easily taken off if there is movement of winding noticed. Secondly, as it is put on hot and slid over the winding, there is nothing to show if the insulation remains as perfect as one could wish. An even quality of metal is uncertain, and so is the loading, because the windings may not be bearing upon it evenly, which may cause an excessive local stress; whilst it is uncertain if it holds the winding down hard against the winding drum.

The advantages of wire are as many. Its uniform quality can usually be guaranteed, and a flaw can be noticed when put on. The winding on of the band in no way disturbs the insulation underneath, and at the same time presses each individual conductor down hard into its place, and so gives less chance of movement. If there is a possible excessive local stress, the material can be of a more ductile nature than is obtainable in the solid rings.

The disadvantages with wire are that it takes longer to put on, and that the ends need to be firmly anchored. The first is set off by the ease with which it may be taken off and put on again, and the latter point is not one of great difficulty. Even during a burst the wire is superior to the solid ring; for if the wire does burst it comes off in small pieces which cannot do much damage; but if the solid ring bursts it will probably break the stator end shields and there is no telling where its travels may end.

It is not advisable to use round wire for the bands, as it has a smaller space factor than square or rectangular wire, and if it is of greater section than No. 16 gauge, the ends will need to be mechanically anchored, in which case a rectangular section, say $\frac{1}{16}$ in. × $\frac{1}{4}$ in., is far easier to handle. With regard to the tension on the wire when winding, the analogy is scarcely that of the wire gun where the wire is wound upon a solid base and the tension increased from the inside to outside. With the winding of wire upon insulation the reverse should be the process because of the yielding base, and further a break in the wire is to be preferred on the inside where it cannot get loose to the outside, when it would make all come loose.

A burst band is, however, not always caused by the weakness of the band itself, but may be the result of an arc starting in the winding and burning through the band or part thereof.

Commutators.

The ordinary vee-ring commutator has been very successful on the ordinary-speed machines, but it is doubtful if it has ever been successfully built for turbo-speeds. Indeed the shrink-ring type of construction has found favour for very long commutators upon normal speed machines.

Rings shrunk upon the outside periphery of a cylinder of commutator segments, with an interposed band of insulation, constitute a shrink-ring commutator. The whole appears a beautifully solid unit that only needs proper mounting and connecting to the armature

windings. The majority of the usual defects are traceable to the commutator, and it appears to the author to be of the greatest importance that this should not only be carefully built, but also correctly designed.

There are two types of commutator, the axial and the radial face. The latter is a splendidly conceived design, but offers some different aspects of design, and is essentially easier than that of the axial face. They both, however, offer the same problem in mounting; and the axial commutator only is considered here, as this is the more common and complex of the two.

Building and Construction.

The building and construction of these commutators call for great care in workmanship. The segments after proper preparation are assembled in jigs in the usual manner, whilst care is taken that the segments lie parallel to the axis of the cylinder. The insulating segments contain as a rule a quantity of superfluous varnish, and this is got rid of by successive bakings and tightening of clamps. The whole whilst still in clamps is next turned for the insulating bands under the rings, and banded with temporary bands of steel wire upon that portion of face where the shrink rings do not come. These bands must not be thick enough to prevent the shrink rings passing freely over them. The insulating bands are next built up in place, banded with fine steel wire, and the clamps removed. The shrink rings are then shrunk on and the whole cylinder is machined where needed and mounted upon the rotor.

The advantages of having a non-inflammable surface of fine wire for the ring to shrink on is easily apparent, but doubts have been expressed as to the advisability of this wire for other reasons, the chief objections being that it will knot and possibly injure the evenness of mica band, or that it will cut the mica itself into pieces. The first point is easily settled from experience, which shows that no effects of this kind are noticeable. The same is found with the second objection, but it will generally be noticed that the pressure upon each wire, say of No. 28 gauge, will seldom exceed 100 lbs. per inch of length. In fact, when an experimental ring was cut it was found that the hot shrink ring had annealed the wire and partially flattened it, and that beyond a distinct marking of the mica there was no sign of any cutting. Further, if the ends of wire were left sticking out beyond the ring, it was found impossible to pull any out from under the ring, because the wire sooner broke where it was held at all.

It is the practice of some manufacturers to leave the insulating bands projecting beyond the rings, whilst others prefer to turn the mica off flush with ring. The latter makes a thoroughly good job, and when new the breakdown voltage, rings to segments, under these conditions is practically the same that is required for an air-gap equal to the thickness of insulating band, *i.e.*, 1,000 volts per $\frac{1}{8}$ in. However, after running some time this mica face becomes coated with dust, and

becomes dangerous if allowed to get too dirty. Similar machines, however, have been run for years without any trouble from this source, probably because it is so easy to clean the surface of the mica by merely wiping it when cleaning the commutator.

A projection of the mica beyond the ring certainly increases the creepage surface, but for this surface to be efficient it must be smooth and free from interstices. To attain this end it is not sufficient to leave the mica projecting beyond ring when shrinking on and use this for the finished projection, as it springs up and is very loose and springy; but the shrink ring should be cut away from the mica, which is then left lying close and compact against the copper face. The length of projection possible can only be deduced from practice, but theoretically it varies as follows :—

$$\text{Length of projection} = \frac{\text{constant}}{(\text{diameter of commutator})^4 \times \text{velocity}^2}.$$

Insulating Segments.

It is most important in choosing the micanite segments to get them as free from superfluous varnish as is practicable. Frequently the effect of this varnish is only seen in the shrinking on of the rings when the high temperature evaporates the caged spirit, which, bursting out, blows out pieces of mica. It has been proposed to use pure mica strip instead of micanite for this purpose, and to use several pieces per segment to avoid the high cost of large pieces. This should produce good results, but would necessitate greater care in assembling.

There has recently been put upon the market a form of micanite that has no varnish in its composition, and although dearer, is much to be preferred to the ordinary quality. This micanite is stoved at a red heat during its process of manufacture.

In the past it was common practice to anchor the micanite by means of a sharp angle in the copper segments, but this would only tend to break off pieces of mica, and if there is no tangential pressure at that point during running, this micanite will fly out. Pure mica in very thin strips has a high tensile strength—10,000 to 15,000 lbs./sq. in. ; but it is not practicable to reckon on this because of the composite and flaky nature of the micanite. Therefore in designing a commutator we must see that there is always sufficient tangential pressure between copper segments to retain a unit of mica.

Insulating Bands.

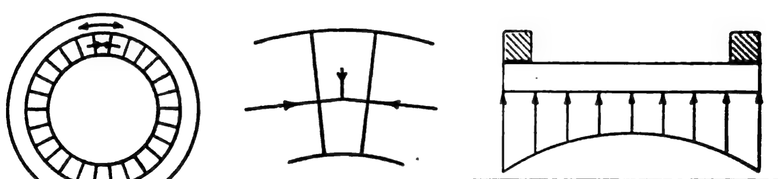
The micanite insulating bands under the shrink rings should preferably be built of strips of segments of pure mica of 20 or 30 mils thickness. Sufficient numbers of these are used by even layering to give the required total thickness of band. The use of shellac or other varnish as a binding material is to be deprecated, as it only introduces an additional yielding substance for the ring to shrink

upon. Under the ring there is no need for any binding cement; and at the edges varnish would have little effect in binding the laminæ at running temperatures, which are generally high enough to make the varnish soft and plastic.

Theory of Construction of Commutator.

To investigate a turbo-commutator it is best that we should take the simplest possible case, and then from its theory deduce the laws and formulæ for others.

The simplest practical commutator is a two-ring, and has a ring at each end of the segments. As the rings are shrunk on, there will be a hoop tension therein, and a corresponding reaction or hoop compression in the segments—Fig. 5 (*a*). The compression hoop stress in segments may be resolved into a series of radial forces tending to drive each segment out again—Fig. 5 (*b*). Further, it is noticed the compression stress is not necessarily limited to that



(*a*) (*b*) (*c*)

Fig. 5.

portion of segments immediately under the ring, but is distributed along the segments. Hence, as there is a force pushing each segment out again, and as each segment is not absolutely rigid, it will bend, and by that means lower the compression stress at that point of segment proportionally to the amount it deflects. The degree of loading upon each segment pushing it out again will vary, and the maximum load is at the ends where there is no deflection and a minimum at the middle where there will be the greatest deflection—Fig. 5 (*c*).

The line of deflection of any approximately evenly loaded beam of even section approximates to a parabolic curve, so that practically we shall not be much in error if we assume that the degree of loading follows in every case the similar curve. Upon taking a case such as we meet in a commutator, and assuming that the total reaction is the constant, we find that by increasing the length of span, ultimately we must reach a particular length such that the reaction in centre of span becomes zero.

The formulæ for the deflection of a beam of even section where

the load varies from zero in centre of span to maximum at ends such that—

$X =$ distance of point from centre of span
$w =$ load per unit length $= X^2$

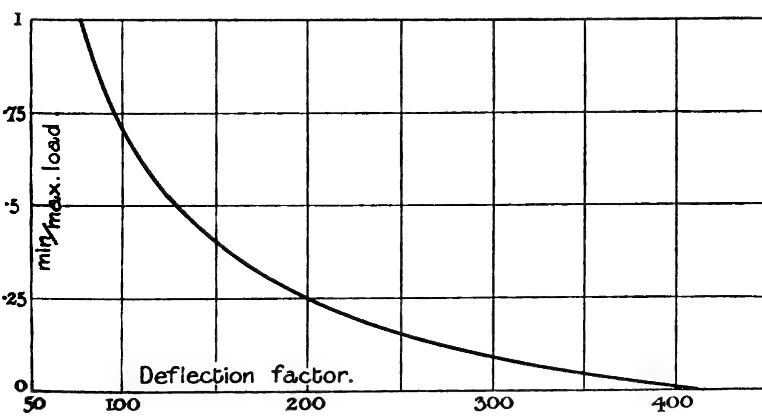
is—

$$\text{max. deflection} = \frac{W L^3}{137 E I} \text{ (see Appendix I.)};$$

where W is the total load, and where h is the maximum load intensity we get—

$$\text{max.} = \frac{h L^4}{411 E I} \text{ (see Appendix I.)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The different values of the factor in the denominator are given by Curve I. for any value of min./max. load.



CURVE I

h is not the same as the tangential pressure, but is a function of the number of segments.

Where $H =$ tangential pressure, and $N =$ No. of copper segments per circle—

$$h = \frac{2 \pi H}{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

or conversely—

$$H = \frac{h N}{2 \pi}.$$

Let the depth of bar corresponding to any span L be such that the degree of load in centre of span is zero, and that it rises thence to a maximum h at end of span; let this depth of bar be A.

The reduction in diameter due to shrinking, which is twice the deflection of one segment, in terms of maximum tangential pressure—

$$= \frac{H\,L_m}{\pi\,E_m} + \frac{H\,L_c}{\pi\,E_c},$$

and in terms of maximum radial loading—

$$= \frac{h\,N^2\,T_m}{2\,\pi^2\,10^6} + \frac{h\,N\,(\pi\,D - N\,T_m)}{2\,\pi^2\,16{\cdot}5\,10^6} \quad \ldots\ldots \quad (3)$$

E_m = Young's modulus for mica = 10^6.
E_c = Young's modulus for copper = $16{\cdot}5 \times 10^6$.
L_m = length of mica in mean circumference.
L_c = length of copper in mean circumference.
T_m = thickness of one mica segment.
D = mean diameter of commutator bars.

Then by equating half of (3) with (1) we may obtain a formula connecting A and L (span) for any commutator :—

$$\frac{1}{2}\left(\frac{h\,N^2\,T_m}{2\,\pi^2\,10^6} + \frac{h\,N\,(\pi\,D - N\,T_m)}{2\,\pi^2\,16{\cdot}5\,10^6}\right) = \frac{h\,L^4}{411\,E\,I}$$

$$= \frac{h\,L^4\,12}{411\;16{\cdot}5\;10^6\,A^3\left(\frac{\pi\,D - N\,T_m}{N}\right)}$$

$$7800\,L^4 = 411\,A^3(\pi\,D - N\,T_m)\,(15{\cdot}5\,N\,T_m + \pi\,D)$$

$$A = 2{\cdot}67\sqrt[3]{\frac{L^4}{(\pi\,D - N\,T_m)\,(15{\cdot}5\,N\,T_m + \pi\,D)}} \quad \ldots \quad (4)$$

Having obtained the value of A for any particular commutator, we may now easily find the condition of loading min./max. for any increased value of A.

Let Z be any new degree of min./max. loading, then the new deflection for an increased value of A will be $= 1 - Z$.

Let $A\,x$ be any increased value of A.

Then original deflection for A—

$$\frac{h\,L^4\,12}{411\,E\,A^3} = 1.$$

New deflection—

$$1 - Z = \frac{h\,L^4\,12}{K\,E\,(A\,x)^3}$$

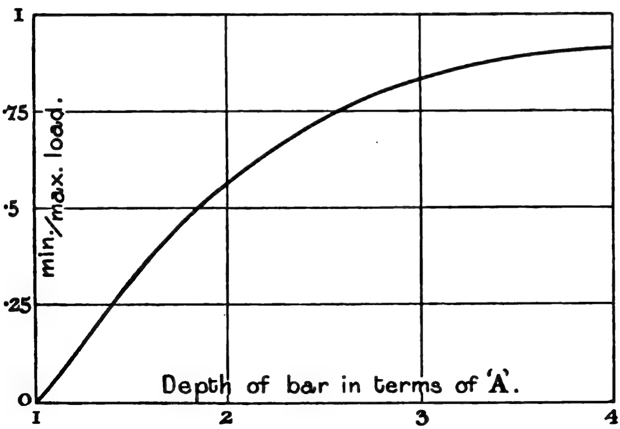
$$\frac{h\,L^4\,12}{K\,E\,(A\,x)^3} = \frac{(1 - Z)\,h\,L^4\,12}{411\,E\,A^3}$$

$$\frac{1}{K\,x^3} = \frac{1 - Z}{411}$$

$$x = \sqrt[3]{\frac{411}{K\,(1 - Z)}}$$

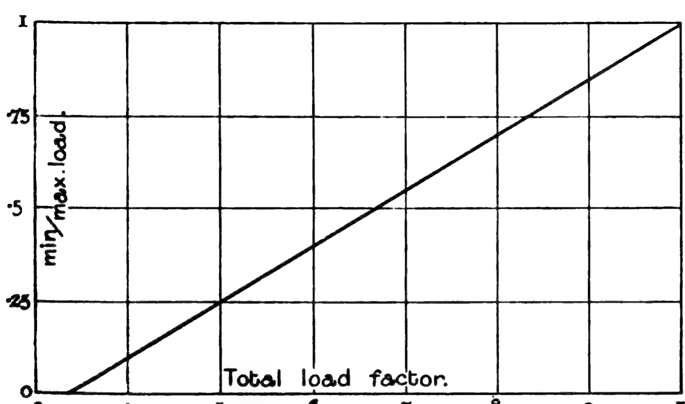
where K is the constant of deflection for the new degree of loading.

These values of A are plotted on Curve II., and Curve III. gives the total area of loads diagram in terms of maximum load into length for all values of min./max. load.



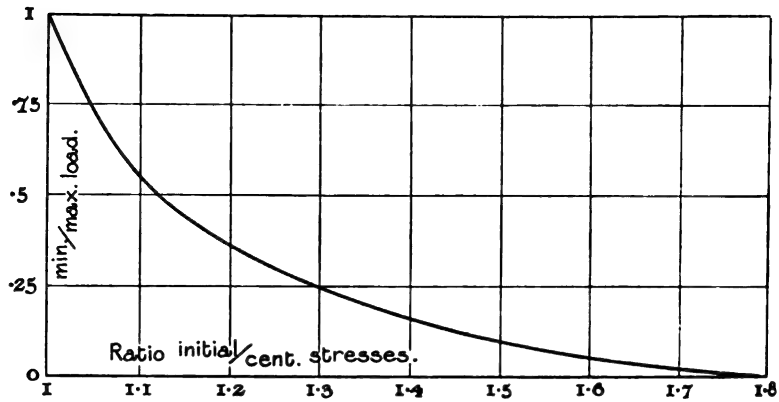
CURVE II.

It is a criterion of good construction in a commutator that there must be no loosening of any part when run up to speed. We must therefore see that the initial deflection given to the bars is always as great as that due to centrifugal forces.

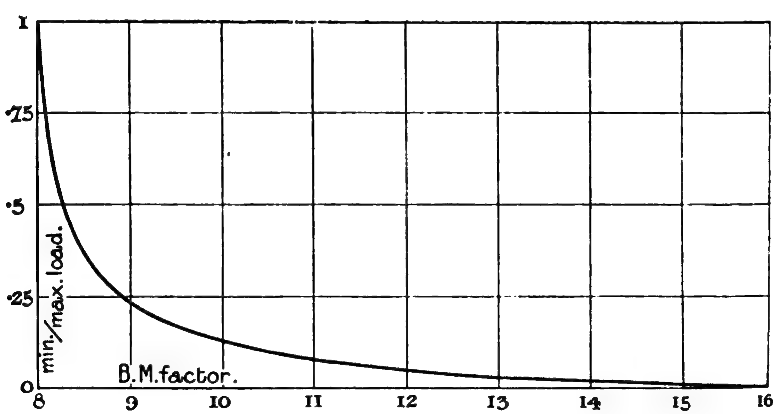


CURVE III.

Let the deflection due to centrifugal forces be δ_1 and the deflection due to initial shrinkage or rings be δ_2. Then to satisfy the specified conditions δ_2 must be not less than δ_1.



CURVE IV.



CURVE V.

The ratio of initial stress in rings to the centrifugal stress is obtained by equating these two deflections :—

$$\delta_1 = \frac{5}{384}\,\frac{W_1 L^3}{E I}$$

$$\delta_2 = \frac{W_2 L^3}{C E I}$$ (where C is a constant for any particular loading min./max.)

$$\frac{\delta_1}{\delta_2} = \frac{C E I}{W_2 L^3}\,\frac{W_1 L^3}{76{\cdot}8\,E I}$$

$$1 = \frac{C\,W_1}{W_2\,76{\cdot}8}.$$

∴ Ratio initial to centrifugal stress in rings—

$$\frac{W_2}{W_1} = \frac{C}{76{\cdot}8}.$$

These values are plotted on Curve IV.

Curve V. gives the constant for bending moment in formulæ—

$$\text{B.M.} = \frac{W L}{C}$$

for any value min./max. load ; whence the initial bending stresses in bars are easily found.

From the preceding theory of construction it will be noticed that in calculating the expansion stresses the simple area of bars should not be used in the calculations, but rather a reduced area of same corresponding to the area of load diagram. Thus in a two-ring commutator with a depth of bar corresponding to A it will be seen that the expansion stresses may be three times greater than if simply the area of bars had been used.*

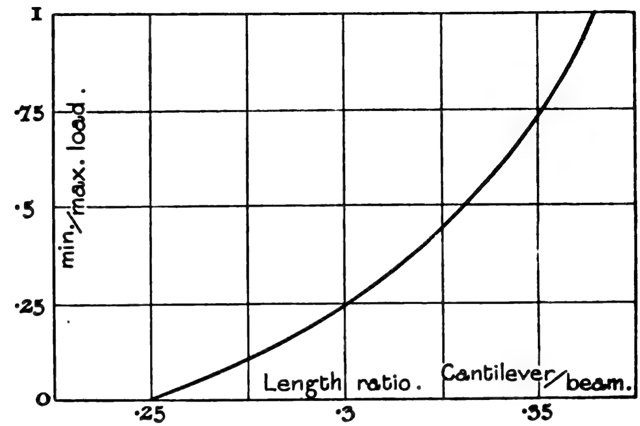
Since every bar of a commutator treated as a beam will contain a simply supported beam, we may conveniently treat all other designs comparatively with that of a two-ring. Thus each end span of a three-ring commutator is equivalent to a simple beam, as we have already considered, and a cantilever supporting one end of the simple beam. The middle span of a four-ring commutator consists of a simple beam supported at the ends of two cantilevers.

The length of a cantilever relative to the span of the simple beam is given by Curve VI. for values of min./max. load in simple beam only (see Appendix II.).

Curve VII. gives the ratio of initial bending moment in cantilever to that in the simple beam.

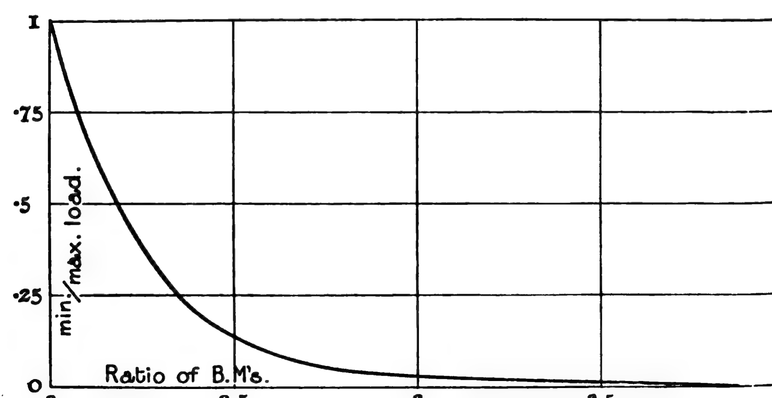
* R. Livingstone, "The Mechanical Design and Construction of Commutators." London, 1907.

Curve VIII. gives the ratio of reaction upon centre ring to that upon an end ring of a three-ring commutator given in terms of min./max. load upon the simple beam only.



CURVE VI.

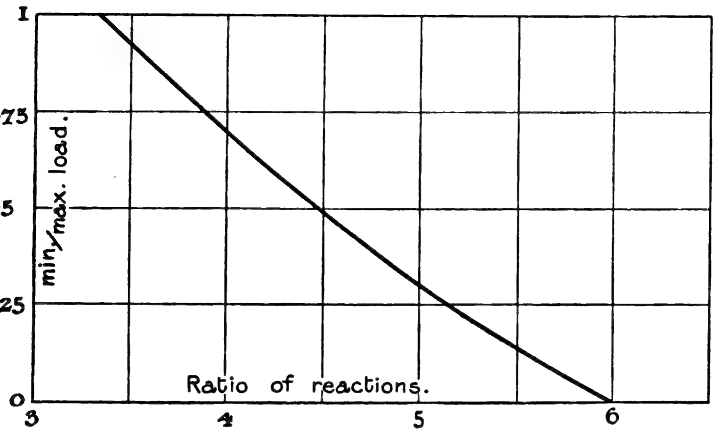
Curve IX. gives the ratio of maximum intensity of load on middle ring to that on an end ring, also in terms of max./min. load on simple beam only.



CURVE VII.

The value of A in a span other than that of a simple commutator is easily got by trial and error. The length of total span for a simple two-ring commutator is best taken as the length from outside

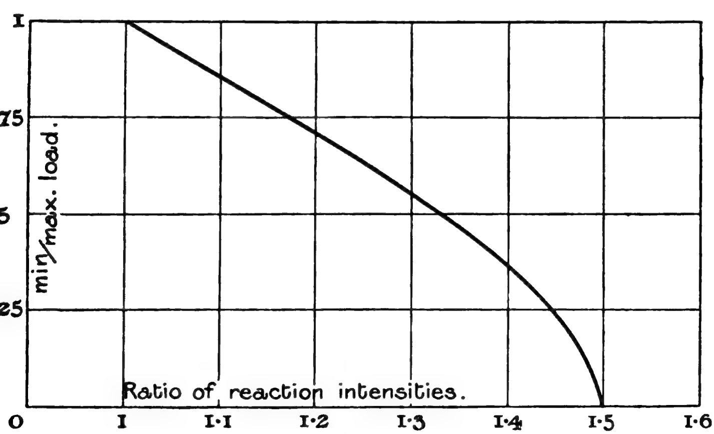
of ring to outside of ring; for a three-ring commutator, from outside of end ring to middle of middle ring; and for the middle span of a four-ring commutator from the middle of each ring.



CURVE VIII.

COMMUTATOR RING SHRINKAGE.

The theoretical shrinkage allowances may be found by summing up the decrease in diameter of the bars due to the maximum tan-



CURVE IX.

gential pressure and the increase in diameter of the ring due to the expected initial stress therein. This will be found, as a rule, to give too small a value for the shop to work to, because of the unevenness of the

mica band, or rather the want of circularity of the wire band over mica caused by uneven layering of mica; hence something must be added to the values found to allow for this, as well as for the lack of elasticity of the mica band and segments. The necessary shrinkage allowance, therefore, should be got only from experience, but with a knowledge of the theoretical shrinkage allowance and past experience it is possible to adjust actual allowances to give the best results.

The actual initial stress in rings may be found by measuring the strain after shrinking. This may conveniently be done by drilling a series of small holes in the sides of the rings. A series is needed because the rings after shrinking are seldom truly circular.

With some designs of commutators it is not possible to allow sufficient shrinkage allowance on the rings. This difficulty may be overcome by using a hydraulic press to make the rings smaller while still hot and in place on the commutator. Although these presses are reported to be in use on the Continent the author has not heard of them being used in England.

Commutator Mounting.

The supports of the commutator upon the shaft of the generator are important, and are generally found to have been the cause of much trouble. The usual method, which has many slight variations, is to mount it upon two metal cones insulated with micanite, one at each end of the commutator.

The first possible trouble comes from the expansion of the bars themselves, which by several heatings and coolings may ultimately grind the micanite to a powder. It has been claimed that by suitable selection of the taper of the cones this is overcome in practice, which is quite probable; but such a series of expansions and such different combinations of expansions may occur that theoretically this is not possible.

Again, some designs are found with the bars not tapered, but left parallel and shrunk upon a uniform sleeve of micanite. This shrinking process is an extremely difficult one to carry out successfully, and if it is not well done, the diametrical expansion of commutator will make it quite loose upon its supports, possibly sufficient to upset the balance of the whole machine; for it must be remembered that there occur diametrical as well as longitudinal expansions.

Some makers use a spring washer behind one of the tapers to take up the longitudinal expansion, but this may be a danger rather than a remedy unless the tangent of the angle of taper is more than the coefficient of friction between micanite and copper or iron.

Commonly, it is found that the diameter of the shaft under the commutator is smaller than it should be for a perfect shaft, and the difference in slope of the line of deflection of the shaft at the two ends of the commutator is appreciable. This causes a great grinding

action on the mica at each revolution of machine, and is augmented if there is vibration when running through the critical speeds. This is not eliminated by any selection of taper, and the only design the author has heard of that does eliminate this trouble is that of Messrs. Parsons, by which the whole commutator is hung by steel discs from the shrink rings, a construction, however, that calls for great care in design.* There are many machines running, nevertheless, where this grinding effect has not been experienced even after years of use. These successes may be attributable to a thoroughly stiff shaft where most needed under the commutator, rendered possible by the use of a high commutator peripheral speed. In general, it may be said that the shaft should be kept fairly uniform in the middle of span, and should not be reduced to permit a small diameter of commutator.

Commutator Risers.

The commutator risers are generally asked to perform two functions—firstly, to carry the current from winding to commutator, and secondly, to act as a fan to draw air through rotor core for cooling purposes. The risers should be flexible and strong or else breakages will occur. Sometimes they are solid except for the end where connected to windings, and sometimes flexible right from the commutator to winding. With the latter design their centrifugal forces must be taken by the rotor banding, which becomes difficult of attainment if the ends must be left uncovered for the passage of air.

Of recent years it has become the practice to use a separate fan for the purpose of ventilation, which is quite distinct from the winding and is mounted either upon a shrink ring of the commutator or the rotor end-plate. This solution of the problem allows the risers to be made very flexible, and covered by band.

Commutator Cooling.

The cooling of commutators on turbo-generators is a great problem and one that has lately brought forward many solutions. The neatest of these is Messrs. Siemens' design where the cooling air is brought through the commutator segments themselves by means of axial ducts therein, and drawn through by a fan placed in the middle of the commutator. The early commutators had none of these devices, but the rings themselves acted as fairly efficient fans and drew the air off the commutator whilst fresh cool air took its place. An increase in the height of the rings increases this effect, but only until the height of ring above commutator surface becomes about one-third the distance between rings, after which the cooling becomes sensibly less efficient.

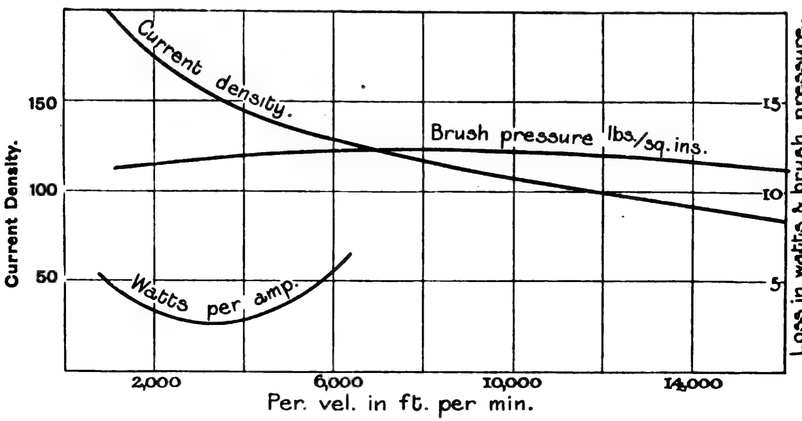
Brush-gear.

Current collection and commutation has always been and still is a rich field for experiment and investigation. Especially is this the case

* An early design of this type is embodied in Messrs. Brown, Boveri's (British) Patent of July 11, 1908. D.R.P., Nov. 9, 1907.

with high peripheral speeds. One of the best published results of experiments is given in a paper by Messrs. Rutherford and Cottle*; but even here, though the experimenters took the greatest care, they were unable to obtain consistent figures for the friction loss. However, the noticeable point obtained was the possible use of higher contact current densities with greater brush pressure for the higher peripheral speeds.

Curve X. gives their suggested values of current density and brush pressures deduced from their results. The loss per ampere collected was fairly regular up to a peripheral speed of 5,000 ft. per minute, after which the results appeared to follow no definite law. Current



CURVE X.

collection and commutation are two different problems, and their comparison is outside the scope of this paper.

The wearing away of the brush upon the commutator face is to be expected, but it is quite common to find that there occurs considerable abrasion of carbon against the holder itself. This is, of course, due to the brush pressing against the holder and the inequality of surface of commutator or even vibration of holder itself producing the movement. Whatever type of brush-holder is used, experience has shown that the brushes should preferably not be supported on the bearing because the latter transmits the rotor vibrations which may be greatly amplified in the brush-gear generally. Attempts have been made to reduce the wear in the box by sloping the brush against the rotation of commutator, but this makes the computation of losses more difficult, if results of experiments with radially placed brushes are to be referred to.

* *Journal of the Institution of Electrical Engineers*, vol. 45, p. 679, 1910.

CONCLUSION.

To look forward to probable improvements of construction we see that one of the ultimate aims is the decrease in span between bearings. This may lead to a reversion to the Eickemeyer or butterfly winding for armature, with the equalisers possibly combined in the end connections. The core may be mounted and the slot wedges constructed as suggested above, or some new material of construction may be found. The radial type of commutator is possibly the ultimate general design, but it will be some years before this type is generally adopted, and in the meantime we may effect great improvements by the

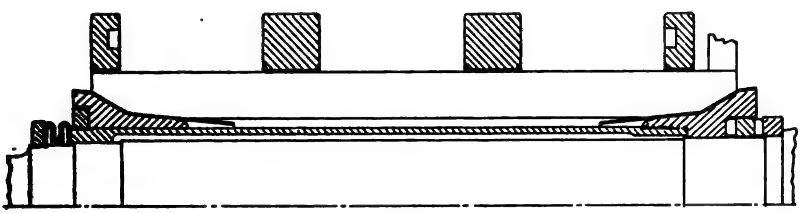


FIG. 6.

use of higher brush pressures and higher current densities and peripheral speeds. A suggestion for mounting of commutator is shown in Fig. 6. The brush-holders are yet very far from perfect, and possibly the present almost universal box-type holder will disappear for some form of the old lever-type holder.

The present ventilating schemes need much improvement, and an air-cooling system with a separately driven circulating fan is a probable solution.

The author is far from taking a pessimistic view of the future of direct-current turbo-generators, and he believes that it is possible to make them as reliable as any other electrical machine. He is of opinion that their mediocre performance in the past has been caused by an inadequate comprehension of the mechanical problems.

APPENDIX I.

Deflection of a beam of uniform section loaded in such a manner that the load per unit length decreases with an increase in deflection.

Let B C be any beam of uniform section supported at the points B and C (Fig. 7). Let the load per unit length be a maximum

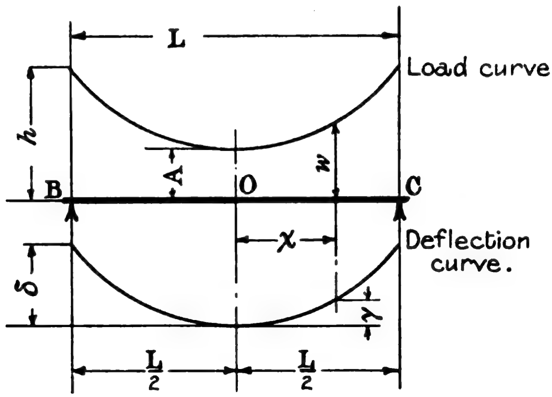


FIG. 7.

at points B and C and a minimum at the centre of beam O. Let the decrease in load from B to O and C to O be proportional to the increase in deflection.

The form of the line of deflection, when the load per unit length in the centre of beam is zero, approximates very closely to that of a parabola, and we shall not be very much in error if, for every value of min./max. load, we assume that the line of deflection is parabolic.

Taking the origin "O" at the centre of the beam—

$$w = A + Kx^2.$$

where—

w = load per unit length.
A = minimum value of load per unit length.
K = any constant.
x = the distance of any point D from O.
y = deflection of point D with respect to O.

$\therefore y$ becomes a maximum when $x = \frac{L}{2}$.

$$EI\frac{d^4y}{dx^4} = w$$

$$= A + Kx^2.$$

$$EI\frac{(d^3y)}{dx^3} = (A + Kx^2)dx$$

$$EI\,d\frac{d^3y}{dx^3} = Ax + \frac{Kx^3}{3} + C_1$$

$$= O \text{ when } x = O; \quad \therefore C_1 = O.$$

$$\mathrm{E\,I}\frac{d^2y}{dx^2} = \frac{\mathrm{A}x^2}{2} + \frac{\mathrm{K}x^4}{12} + \mathrm{C}_2$$

$$= 0 \text{ when } x = \frac{\mathrm{L}}{2}$$

$$\therefore\ \mathrm{C}_2 = -\left(\frac{\mathrm{A\,L}^2}{8} + \frac{\mathrm{K\,L}^4}{192}\right)$$

$$\mathrm{E\,I}\frac{d^2y}{dx^2} = \frac{\mathrm{A}x^2}{2} + \frac{\mathrm{K}x^4}{12} - \frac{\mathrm{A\,L}^2}{8} - \frac{\mathrm{K\,L}^4}{192}$$

$$\mathrm{E\,I}\frac{dy}{dx} = \frac{\mathrm{A}x^3}{6} + \frac{\mathrm{K}x^5}{60} - \frac{\mathrm{A\,L}^2x}{8} - \frac{\mathrm{K\,L}^4x}{192} + \mathrm{C}_3$$

$$= 0 \text{ when } x = 0;\quad \therefore\ \mathrm{C}_3 = 0.$$

$$\mathrm{E\,I}\,y = \frac{\mathrm{A}x^4}{24} + \frac{\mathrm{K}x^6}{360} - \frac{\mathrm{A\,L}^2x^2}{16} - \frac{\mathrm{K\,L}^4x^2}{384} + \mathrm{C}_4$$

$$= 0 \text{ when } x = 0;\quad \therefore\ \mathrm{C}_4 = 0.$$

$$v = \frac{1}{\mathrm{E\,I}}\left(\frac{\mathrm{A}x^4}{24} + \frac{\mathrm{K}x^6}{360} - \frac{\mathrm{A\,L}^2x^2}{16} - \frac{\mathrm{K\,L}^4x^2}{384}\right)$$

$$y_{\text{max.}} = \frac{1}{\mathrm{E\,I}}\left(\frac{\mathrm{A\,L}^4}{384} + \frac{\mathrm{K\,L}^6}{23040} - \frac{\mathrm{A\,L}^4}{64} - \frac{\mathrm{K\,L}^6}{1536}\right)$$

$$= -\left(\frac{1}{\mathrm{E\,I}}\,\frac{5\,\mathrm{A\,L}^4}{384} + \frac{14}{23040}\,\mathrm{K\,L}^6\right);$$

when A = O—

$$y_{\text{max.}} = -\frac{14}{23040}\,\mathrm{K\,L}^6.$$

The total load on both sides of origin—

$$= 2\int_0^{\frac{\mathrm{L}}{2}} w\,dx = 2\int_0^{\frac{\mathrm{L}}{2}} (\mathrm{A} + \mathrm{K}x^2)\,dx$$

$$= 2\left(\mathrm{A}x + \frac{\mathrm{K}x^3}{3}\right)_0^{\frac{\mathrm{L}}{2}}$$

$$= 2\left(\frac{\mathrm{A\,L}}{2} + \frac{\mathrm{K\,L}^3}{24}\right)$$

$$= \mathrm{A\,L} + \frac{\mathrm{K\,L}^3}{12}.$$

w has a maximum value when $x = \frac{\mathrm{L}}{2}$

$$w_{\text{max.}} = h = \mathrm{A} + \frac{\mathrm{K\,L}^2}{4};$$

when $A = O$ and $K = 1$—

$$h = \frac{L^2}{4}.$$

Total load, when $A = O$ and $K = 1$—

$$= \frac{L^3}{12} = \frac{L^3}{12} \times \frac{4}{L^2} \times h$$

$$= \frac{h\,L}{3}.$$

Maximum deflection, when $A = O$ in terms of h and L—

$$\delta_{max.} = \frac{14\,K\,L^6}{E\,I\,23040} \times \frac{12}{K\,L^3} \times \frac{h\,L}{3}$$

$$= \frac{h\,L^4}{411\,E\,I}.$$

APPENDIX II.

Deflection of a beam of uniform section built in at both ends and loaded so that the load per unit length has a maximum value at the points of support and a zero value at the point of greatest deflection,

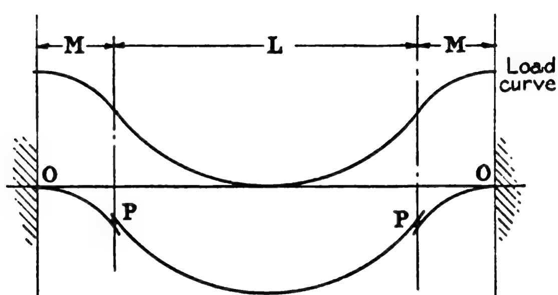


FIG. 8.

the load decreasing between these points proportionally to the increase in deflection.

Let O.O. be a continuous beam of uniform section built in at point O and O and loaded, as described, so that the load per

unit length has a maximum value A at O and O, and a zero value in the centre of beam (Fig. 8). For treatment the beam may be split up at the points of inflection P and P, and will consist of a beam P P, loaded as treated in Appendix I., when the minimum load per unit length is zero, supported at the ends of two cantilevers O.P. and P.O. Each cantilever then will be loaded with a concentrated load at ends and also with a varying distributed load.

Let O.P. be one of these cantilevers, loaded with a concentrated load Z, which is the reaction of loaded beam at P, and also with a

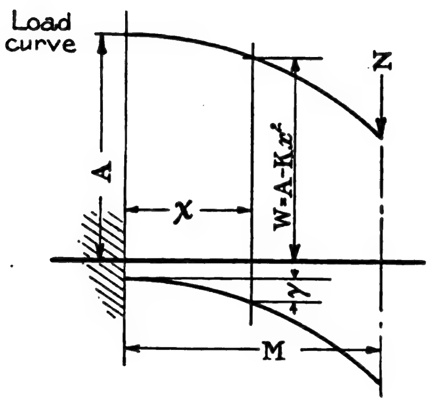


FIG. 9.

varying load. If we make the same assumptions as in Appendix I. that the line of deflection is parabolic, we get the load per unit length (Fig. 9):—

$w = A - K_2 x^2$.

K_2 and $A =$ any constants.

$x =$ distance of any point F from O.

$y =$ deflection of point F with respect to O.

Neglecting Z—

$$E I \frac{d^4 y}{d x^4} = w$$

$$= A - K_2 x^2$$

$$E I \frac{d^3 y}{d x^3} = A x - \frac{K_2 x^3}{3} + C_1$$

$$= O \text{ when } x = M.$$

$$\therefore\ C_1 = -AM + \frac{K_2 M^3}{3}$$

$$EI\frac{d^2y}{dx^2} = \frac{Ax^2}{2} - \frac{K_2 x^4}{12} - AMx + \frac{K_2 M^3 x}{3} + C_2$$

$$= O \text{ when } x = M.$$

$$\therefore\ C_2 = -\left(\frac{AM^2}{2} - \frac{K_2 M^4}{12} - AM^2 + \frac{K_2 M^4}{3}\right)$$

$$= \frac{AM^2}{2} - \frac{K_2 M^4}{4}.$$

By adding the B.M. due to Z we obtain the total B.M. on cantilever—

$$EI\frac{d^2y}{dx^2} = \frac{Ax^2}{2} - \frac{K_2 x^4}{12} - AMx + \frac{K_2 M^3 x}{3} + \frac{AM^2}{2}$$
$$- \frac{K_2 M^4}{4} + ZM - Zx. \quad \ldots \ldots \quad (3)$$

$$EI\frac{dy}{dx} = \frac{Ax^3}{6} - \frac{K_2 x^5}{60} - \frac{AMx^2}{2} + \frac{K_2 M^3 x^2}{6}$$
$$+ \frac{AM^2 x}{2} - \frac{K_2 M^4 x}{4} + ZMx - \frac{Zx^2}{2} \quad \ldots \ldots \quad (4)$$

The slope at P is obtained when $x = M$.

$$\frac{dy}{dx} = \frac{1}{EI}\left(\frac{AM^3}{6} - \frac{K_2 M^5}{60} - \frac{AM^3}{2} + \frac{K_2 M^5}{6} + \frac{AM^3}{2}\right.$$
$$\left. - \frac{K_2 M^5}{4} + ZM^2 - \frac{ZM^2}{2}\right)$$

$$\frac{dy}{dx} = \frac{1}{EI}\left(\frac{AM^3}{6} - \frac{K_2 M^5}{10} + \frac{ZM^2}{2}\right) \quad \ldots \ldots \quad (5)$$

From Appendix I. we obtain the slope of beam at P when $x = \frac{L}{2}$

$$\frac{dy}{dx} = \frac{1}{EI}\left(\frac{AL^3}{48} + \frac{KL^5}{1920} - \frac{AL^3}{16} - \frac{KL^5}{384}\right);$$

when $A = O$ and $K = 1$

$$\frac{dy}{dx} = -\frac{1}{480}\frac{L^5}{EI} \quad \ldots \ldots \quad (6)$$

Equating (5) and (6) and changing sign in (6)—

$$\frac{A M^3}{6} - \frac{K_2 M^5}{10} + \frac{Z M^2}{2} = \frac{L^5}{480}.$$

To solve this equation of several unknowns, it is simplest to put a particular value for L, whence follows a value for z; and try different values for M, whence come K_2 and A, and so obtain the correct answer by trial and error—

$$M = 0{\cdot}25\ L \text{ (very nearly)}.$$

Having obtained a value for M it is a simple process, by a further integration of (4), to obtain the deflection of P. Then the maximum deflection of whole beam is got by adding the sum of deflections of cantilever and beam.

Discussion.

Mr. R. Livingstone: The defects mentioned on page 128 by no means cover all defects, though the ones mentioned are certainly common. An important defect, which I have frequently seen in high-speed machines, is in the design of the oil throwers for the bearings. They are often made so that they throw the oil violently from the shaft against the bearing housing. The result is, some of the oil is sprayed and some splashed back to the shaft of the wrong side of the thrower. This oil travels along the shaft to the armature or commutator and causes trouble. It is much better to avoid the use of oil throwers and rely on oil glands for retaining the oil in the bearing housing. The usual arrangement of ventilation described in the paper is certainly economical so far as first cost is concerned, but above a certain output it is not a good arrangement with regard to efficiency. The efficiency of fans running at peripheral speeds of 12,000 to 18,000 ft. per minute is in the neighbourhood of 10 to 30 per cent., whereas Sirocco fans running at the correct peripheral speeds have efficiencies varying from 45 per cent. in small sizes to 65 per cent. in the large sizes. With separately driven fans the motor efficiency must also be taken into account, but it will be found that when the fan power exceeds about 5 H.P. a saving is effected. Where such a separate-driven fan is used the generator rotor should be made with as little fan action as possible so as to make it easy to guide the air to where it is most required. With air under a pressure of 5 in. water-gauge the horse-power of the fan motor would be (cubic feet per minute)/($1200 \times n$) when n is the fan efficiency. In the table on page 131 this efficiency has been taken as approximately 20 per cent., but with an external fan there should be no difficulty in getting 50 to 55 per cent. even in the small sizes required for turbo-generators. I certainly agree with the author in his statement that all bearings should be regarded as self-aligning, because even if solid bearings stiffen the shaft when new, the bearings wear, Mr. Livingstone.

Mr. Livingstone.

and so permit the shaft to take its normal line of deflection. Bearings for 3,000 revs. per minute machines having a diameter of 4 to 5 in. will run well if the clearance is 50 to 100 per cent. greater than the amount stated by the author. Indeed, it is necessary to have large clearance to provide for the oil film between the surfaces. If sufficient clearance is not provided the friction will be higher than it should be. It is certainly good practice to anneal the shafts before the final cuts are taken, but it should be kept in mind that this annealing reduces the ultimate strength and elastic limit. This, however, would do no harm in a shaft having the physical properties mentioned. All the same, it is questionable if the annealing does everything that is required, because one of the chief causes of warping is the cutting of the keyways, and this is usually done after the shaft is turned. I find that the best practice is to buy shafts rough-turned, oil-toughened, and annealed, and to cut as small keyways as are consistent with the torque. A pressure of 8,000 lbs. per square inch on the laminations is not excessive. Most direct-current machines have to run through the critical speed, and in such cases it is advisable to have the whirling speed two-thirds of the normal speed.

As regards the rotor core, I do not quite understand the author's recommendation to design the shaft and core so that the diametrical stresses are equal. In all cases this is impossible, as the shaft is always of smaller diameter than the core, and is in addition solid, whereas the core is hollow and has to carry the windings. The most that can be done is to keep the tangential stress at the inner surface of the core as small as possible. I have designed rotors with a stress of 12,000 lbs. per square inch in a 3,000 revs. per minute machine, and have not experienced any trouble due to the expanding of the core. At the same time, it is advisable to guard against any possible trouble if at all possible, and I would be glad to see a satisfactory method of providing some elastic medium between the core and the shaft. I would mention, however, that it is possible to press a laminated rotor on to the shaft. I like the slot shown in Fig. 3 (*a*), but I should think the cost of winding would be higher. Fig. 3 (*b*) is not so good, as the load on the tip of the tooth is eccentric, and we all know how hard it is to provide sufficient metal to carry an eccentric load. With good fibre wedges a bending stress of 1,500 lbs. per square inch is not excessive, and so far I have not found the depth of wedge excessive even with ordinary open slots $\frac{3}{16}$ to $\frac{5}{16}$ in. in depth, covering all ordinary machines. Of course with peripheral speeds of 18,000 or 19,000 ft. per minute this depth might be exceeded. It is certainly feasible, though expensive, to use laminated brass wedges; I do not know, however, of any case where this has been tried. As regards the rotor winding, equalising connections are certainly advisable in all parallel-wound armatures, as they do away with the unbalanced magnetic pull, besides making a better electrical machine. I most certainly prefer the solid end bell to binding wire. If the windings are made slightly conical, and the end bell is made the same, the bell is quite easily put on and taken off. It

Mr. Livingstone

is advisable to press the windings into their conical shape on to a conical support formed by the end plate so as to give a true hard surface for the end bell. Very often binding wire is fastened at intervals with solder, and if this is not carefully done the wire is annealed and weakened. A solid bell is more convenient for repairs *in situ*, and it will resist distortion. It is probably easier to shrink a ring on to a metal band than on to the mica ring itself, but the latter method offers no great difficulties and gives satisfactory results. At the same time, having a layer of thin wire between the ring and the mica saves the mica from being slightly charred, and is probably better on the whole.

Perhaps the most valuable part of the paper is that dealing with the theory of construction; the author puts the theory very clearly, and the curves given simplify the working of problems. I have not had time to check the formulæ, but I agree with the reasoning and regret that the considerations are confined to the initial stresses in a commutator. The final stresses in a commutator are made up of initial stress and centrifugal stresses properly combined and also initial centrifugal and expansion stresses properly combined. It is quite correct that the bending of the bars reduces the tangential stresses at the centre of the bar (in a two-ring commutator) and increases it at the ends, and the real solutions for this are valuable. In practice, however, we must start out with the assumption that a certain minimum tangential mica pressure is required on the mica, say 500 lbs. per square inch. Then it will be found that the ratio of depth to length of bar does not vary very greatly, so that the ratio (maximum pressure)/(minimum pressure) is almost a constant. If, however, we start out with the assumption that the average initial pressure is much higher than the minimum, say 1,000 lbs. per square inch, then, for all important stresses we will be on the safe side; because if the rings are shrunk on to give the stress corresponding to the average pressure, the total load will be the same but the distribution will be altered. Therefore, the bending stress and deflection on the bars will be less than calculated, and the stress in the rings will be the same as calculated. The tangential mica pressure at the centre of the bar will be less, and at the ends greater, than calculated, so that on the whole we are not much out, and at the important points we are on the right side. I would here mention that it is difficult to calculate absolute stresses in any machine. What we do do is to calculate figures which we compare with similar figures on a machine which is running satisfactorily, and keep within those limits or only exceed them very slightly. Calculating them on the assumption of a tangential load higher than the theoretical minimum, we can run the bending stresses in the bars higher than we could do so under ordinary conditions, and still have a satisfactory commutator. This does not detract from the value of the author's deductions, but points to the importance of adjusting the usual figures for initial tension in accordance with the new methods of calculation. Again, we must always keep in mind that when the commutator has worn down the

Mr. Livingstone.

mica has been compressed and released many times, and so by breaking down the mica alters its modulus of elasticity.

Mr. Catterson-Smith.

Mr. J. K. CATTERSON-SMITH: I feel that although some of the matter to which Mr. Roberts refers is quite familiar to us, there is other matter which he has somewhat skimmed over in his paper. With regard to the statement on page 131 that the question of shafts of turbo-generators is very easily dealt with, I do not know whether most of the engineers present do consider this question quite so easy. My own experience is that the design of shafts for turbo-machines is not easy. So far as I am aware, the only really satisfactory method of calculating the critical speed is that given by Professor Stodola,* a modification of which has been given by Professor Morley more recently.† Although Professor Stodola's method is a somewhat lengthy one, it is possible by the use

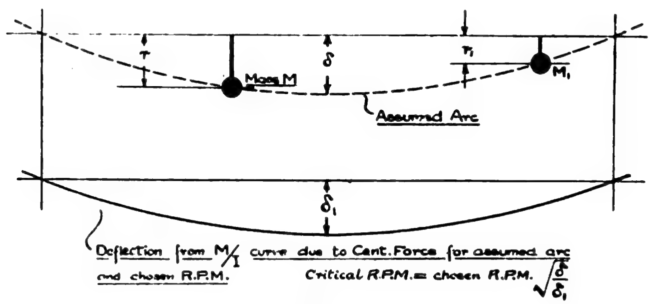


FIG. A.

of a simplification to save a great deal of time without much loss of accuracy. The particular method to which I refer may be stated briefly as follows:—

Take any deflection of the shaft δ and draw an arc of a circle as an approximate deflection curve through the mid-points of the journals and deflected by the amount δ_1 (see Fig. A). Then calculate for each mass M on the shaft its centrifugal force when running at some arbitrary trial speed and at the radius r given by the circular deflection curve, and thus obtain a curve-factor load diagram. As the diameter of the shaft varies greatly, being, in fact, designed for approximately skin stress, it is necessary to allow for the variation of I for each section, and thus draw an M/I curve from which the real deflection curve at the trial speed is drawn having a maximum deflection δ. Then we have for the rotor—

$$\text{Critical revs. per minute} = \text{trial revs. per minute} \times \sqrt{(\delta/\delta_1)}.$$

It will be found that this method gives good results even when the trial speed chosen is very different to the critical speed. If it is desired to

* "Steam Turbines," A. Stodola (Constable and Co., London), 1906.
† *Engineering*, vol 88, p. 135, 1909.

use a trial speed fairly close to the critical speed, a rough figure is given by the expression— Mr. Catterson-Smith.

$$\text{Critical revs. per minute} = 180\sqrt{(1/d)} \text{ approximately,}$$

which is deduced from the case of a simple concentrated mass. The deflection d, in inches, should not, it appears, exceed 1/5000 to 1/8000 of the span. I agree with the author that the bearings generally have enough clearance to be treated as spherical-seated for these calculations. I would like to draw attention to the statements on page 150 regarding the use of high-current densities in the brushes. Curve X shows plotted the results deduced from tests made at the University of Liverpool, and I think these curves are extremely misleading unless it is clearly understood that they refer to tests in which the current is simply collected by brushes from a steel ring, and that they therefore have no reference whatever to the case of a commutator. The curve shown indicates a current density of over 100 amperes per square inch at ordinary turbo-commutator speeds, whereas it is common knowledge that even under good conditions with commutation poles it is rarely possible to guarantee the current-change in the coil undergoing reversal to be a linear function of time, and thus the ordinary nominal density is limited to 40 or 45 amperes per square inch; any departure from the linear current-change law raising the density over parts of the brush to high values of the order of 200 or 300 amperes per square inch, and thus it is quite impossible to work with the high densities indicated on page 150. Reference is made to the possibility of lowering the temperature of the air used for cooling the machine by the passage of that air through some form of refrigerator. I do not know of any case where this has been done in this country, but I have worked out one or two figures as to the size of refrigerator or cooling chamber required, using the ordinary figures which are at present practised by refrigerating engineers, and taking the volume of air as stated by Mr. Roberts at something like 100 cub. ft. of air per minute raised 30° F. per kilowatt loss for the case of a turbo set of 1,500-k.w. capacity made up of two machines in tandem, each of 750-k.w. size and having a loss of 90 k.w. as given on page 131. Two methods of cooling are considered; in the first the air-cooling plant consists of a battery of water pipes through which the air is circulated. The battery receives the hot exhaust from the generator, to which it delivers cool air.

With a cool air temperature of 65° F. and a hot air temperature of 95° F., the quantity of air $= 90 \times 100 = 9{,}000$ cub. ft. per minute. As the air is continuously circulated between the generator and cooler, it may be taken as being fairly dry, and with a specific heat of 0·24 and weighing 0·086 lb. per cubic foot, then heat to be abstracted per minute from air $= 9{,}000 \times 30 \times 0{\cdot}086 \times 0{\cdot}24 = 5{,}600$ B.Th.U. or, allowing for a little moisture, say 6,000 B.Th.U. per minute. With 15-ft. pipes under these conditions a square foot will absorb 0·67 B.Th.U. per minute, and if it is assumed that cold well water at 50° F. is available, then for 10° F. rise in the water we get pipe surface $= 6{,}000/(0{\cdot}67 \times 10) = 900$ sq. ft.

Mr. Catterson-Smith.

That is, with 2-in. pipes, a battery of 120 pipes, which may be stacked in a space 5 ft. high, 3 ft. wide, and 15 ft. long inside. Allowing for the space occupied by the pipes, the air velocity is 800 ft. per minute. The amount of water required for 10° F. rise is 6,000/10 = 600 lbs. per minute. The second method of cooling to be considered is that in which a refrigerator is proposed for the purpose of supplying chilled air to the turbo-generators in a station. As it is possible that this might be advantageous in some cases, the following figures may be of interest. Suppose an ordinary vapour compression refrigerator keeping a brine tank at 30° F. to be installed with a pump to circulate the cold brine through a battery of pipes so that the brine is 30° F., then—

Brine inlet temperature	30° F.
Brine outlet temperature	60 ,,
Cold air to generator...	65 ,,
Hot air from generator	95 ,,
Air per minute as before	9,000 cub. ft.

Pipe surface ... ... $= \frac{6000}{0{\cdot}67} \times 30 = 300$ sq. ft.

That is, with 2-in. pipes, a battery of 40 pipes, which may be stacked in a space 5 ft. high, 1 ft. 6 in. wide, and 15 ft. long, the air velocity now being 1,100 ft. per minute. In view of the trouble experienced through the accumulation of dust and dirt brought in by the cooling air in the ordinary systems, it seems quite possible that one of the above systems, in which the air is perfectly clean and as cool as thought desirable, might well be tried. I should like to emphasise the statement on page 149 regarding the importance of correctly designing the commutator risers. I consider this to be one of the most difficult parts to design satisfactorily, and can recall an instance of a turbo-generator which, on examination after 5,000 hours' run, showed 2½ per cent. of the risers fractured and 25 per cent. in a bad condition, in spite of the fact that much consideration had been given in their design. I quite agree with the author that equalising connections are essential, and would suggest that the number shown in Fig. 4 might be increased with advantage by 50 or 100 per cent. In connection with the process described by the author for assembling the shrink-rings and mica, in which fine steel wire bands are used instead of string with the advantage that the wire surface can be gauged, I would like to say that I have seen thin steel bands put on the mica, and afterwards turned true on the outer surfaces, which were then easily gauged for the shrink-rings.

Mr Everest.

Mr. A. R. Everest: The author mentions the rapid accumulation of dirt and soot which may occur in high-speed machines with forced ventilation, and refers to the difficulty which this may cause in connection with exposed conductors, leading to troubles from leakage and earthing. Further on, he mentions that it is common practice in connection with alternating-current turbo-generators, to clean the air by means of filters before it is passed into the machine, but suggests that these precautions are not so necessary with the direct-current

machine on account of its lower generating voltage. These statements appear hardly consistent. There can be little doubt as to the desirability of filtering the air supply to turbine-driven generators of the direct-current as well as of the alternating-current type. Accumulation of dirt is objectionable not only on account of possible loss of insulation, but also because it interferes with the proper cooling of the plants. On page 129 reference is made to the necessity for properly supporting the stator winding, and an arbitrary figure of 10 in. suggested as the extreme length which should be left unsupported. The author mentioned that this figure was an arbitrary one, and that it would be smaller for a high-speed machine than for one of lower speed. It is not quite clear why this should be so. There is apparently an error in the figures on page 133 referring to the possible looseness which could occur in a rotor due to the expansion of the punchings from centrifugal force. If, in the case assumed, the punchings expanded so that their inner diameter became 0·0038 in. larger than the shaft, then the possible displacement of the centre of gravity would be half this amount, and the resultant out-of-balance also one-half that suggested in the paper. Mr. Everest.

Mr. R. HARRISON: On page 133 the author says that "the stresses occurring in these discs are similar to those occurring in disc flywheels and are capable of similar treatment," but this does not help us to solve that problem. To take first the simple case of a flywheel cast in halves and fastened by plates at the joints, we know that the bursting stress has ceased to be independent of the area of the rim because the curve-factor forces are now spread over a new stress area which is that of the plates. Now the case of the core disc for a high-speed generator is a very similar one. The real disc is, of course, between the bottom of the slots and the top of the keyway, but we know if we got this stress it would not be the true result, because the curve factor of the projections from that disc are also being carried by the effective stress area of the disc. The best method I know of to get an estimate of the true stresses in the perforated disc, is to get the true weight of the disc, using the true density of the material, which is, say, 0·28. Now put this weight into the effective area of the disc, and for most turbo-machines this will give a new density of about 0·35. This generally gives a stress at the inner fibres of the disc of about 10,000 to 12,000 lbs. per square inch, and from this can be obtained the increase in diameter due to rotation, and the least safe shrinking allowance to ensure a tight fit at runaway speed. Referring to the sketch on page 136, Fig. 4, I should like to raise three points for discussion. (1) On page 151 the author says that to look forward to probable improvements of construction we see that one of the ultimate aims is to decrease the span between bearings, and so I am rather surprised to see the equaliser rings placed in the position shown when they could easily be arranged under the end drum, and so shorten the span between bearings. As the deflection is proportional to length cubed, a saving of 3 or 4 in. strengthens the shaft considerably. (2) The second point is that the machine cannot be Mr. Harrison.

Mr. Harrison.

tested without the rings and then have them fitted for the final test. (3) The third point is the enclosing of the soldered joints, which, of course, get very hot. There is a very neat method of overcoming this, but I am afraid I cannot explain without the use of the blackboard.

With reference to page 138, I am rather surprised at the careful attention the author has given to the stresses in the commutator where the results are so uncertain, while the calculations which give more certain results, such as the shaft calculation which takes into account the different diameters along the shaft, etc., have been ignored. The reason the commutator calculation is so uncertain is because the rings are shrunk on mica, and it is almost impossible to judge the amount of mica required so that it will compress exactly to the calculated figure. If we were shrinking a steel tyre on a steel wheel-centre, then we could measure the allowance to 0·005 of an inch, and the calculations would be then quite reliable. With regard to shrinking the core on the shaft, it is as well to note that this has a tendency to make the shaft stiffen, and therefore to increase the critical speed above the calculated value. This teaches us that it is advisable to make the critical speed above the normal running speed where possible, so that if the core-stiffening effect does raise the critical speed it is making the machine still safer.

Mr. Hoult.

Mr. W. HOULT: I notice under the subject "Ventilation" the author states that part of the stream of air for ventilating the turbo-dynamo goes direct to the stator, whilst the greater part goes through the rotor by axial ducts in the core. Part of this rotor air then goes through the radial ducts in the rotor and stator, whilst the other part goes to the commutator. Now, as it is extremely important to keep the commutator of the machine cool, it is better to make the supply of air to the commutator entirely separate from the supply of air that passes through the core, otherwise the air is heated before it gets to the commutator. This supply of air can be brought along the shaft, so that the commutator obtains air at the lowest temperature. As regards the question of air filters, I certainly think that they should be installed wherever the atmosphere contains dirt in suspension. When we observe the dirt that collects on the filter cloth it makes us think how very dirty many turbo-generators must be, as most of this dirt would have been deposited in the ducts and on the windings. Referring to the alternative methods of totally enclosing the machine and cooling either with a water-jacket or freezing plant, I think that a cheaper and better way for large generators would be to draw the air through fine sprays of water and then through a series of vertical corrugated plates, so as to throw off the water. The water, mixing intimately with the air, would take away the particles of dust and also cool it to practically its temperature. The air leaving the baffles will be practically dry and also considerably cooler than the outside air. I do not quite agree with the author when he states that "the whole art of balancing can only be learnt, and not taught." I am convinced that if an engineer attempts to balance a machine, and has certain points put before him by a man who has had considerable experience in balancing, he will

obtain a satisfactory balance very much quicker than he otherwise would do. I should be very pleased if the author would give the method that he usually uses for balancing high-speed machines. It would be very interesting to find out in what manner different people approach the work. Then as regards the wire banding, or solid metal end-winding sheaths, I certainly agree with other speakers before me that the use of binding wire is wrong. The author is right when he says that the "solid sheath looks more like an engineering job," and I believe that it is one. The author states that one of the disadvantages with wire is that it takes longer to put on, and then remarks that this is set off by the ease with which it may be taken off and put on again. Having had experience of both methods, I consider that the putting-on and taking-off of a metal winding sheath is an infinitely easier job than putting on or taking off binding wire. In fact, I consider it a fairly easy job to remove a metal end sheath on site, but I think it very difficult to put on binding wire except at the maker's works. The author also remarks that "even during a burst the wire is superior to the solid ring." Out of about 700 end sheaths that I know have been supplied on turbo-generators, I have never heard of one that has broken, but I have seen several cases of binding wire having come off, and if anybody had been standing by at the time they would most certainly have been seriously injured. I thoroughly agree with the author that the majority of the usual defects are traceable to the commutator, and that it is of the greatest importance this should be carefully built, also correctly designed. On page 148 the author states that the first possible trouble comes from the expansion of the commutator bars. As stated in the paper, Messrs. Siemens bring the cooling air through the commutator segments themselves by means of axial ducts therein. The commutator is usually built in two parts, so that the length of bar is reduced by one-half, and as the cooling surface is at least doubled the usual expansion of the conductor is something like one-quarter of what it would be if single solid bars were used. The trouble of expanding bars with this type of commutator does not arise. It is now recognised that for the successful running of a turbo-dynamo carbon brushes must be used, and as heat causes disintegration of the carbon brushes, which is assisted by the high peripheral speed, this can only be obtained by a cool commutator. Mr. Hoult.

Mr. G. W. Worrall: The paper shows that the problem of the dynamo-electric machines is by no means a purely electrical one, and the mechanical side of the problem is at least of equal importance. The question of commutation, although most abstruse in its electrical aspects, is to a large extent mechanical, and I think had this side of it been more thoroughly understood, the electrical side would have been more easily solved. The mechanical problem of commutation is twofold. In the first place, the frictional force tends to tilt the carbon on to the rear tip; this action is evident in all box-type holders, and its effect is considerably to increase the contact resistance at the forward tip. The bottom edge of the plate in front of the carbon in Mr. Worrall.

Mr. Worrall. the box-type holder acts as a fulcrum about which the force of friction tends to turn the carbon. The controlling force of the pressure applied to the carbon cannot restrain this action until the fulcrum is shifted to the top of the box at the rear edge, which takes place as soon as the pressure of the front tip on the commutator is relieved. The first step in the right direction is to substitute an elastic force for the resisting plate. With this arrangement all the applied forces tend to turn the carbon in the opposite direction to the action of friction. A brush-holder in which this principle is developed is described in my paper on "Commutation Phenomena." * This brush-holder appeared to solve the problem of holding the carbon in a very satisfactory manner. The other problem of commutation which, although perhaps not strictly of a mechanical nature is certainly not electrical, is the expansion of the brush service. The rear tip of the brush is cooled by the air drawn round the commutator, but the front tip is not so cooled, and the expansion of the contact surface due to heating causes this tip to lift from off the commutator surface and set the brush vibrating. The tip may, however, be kept in proper contact by placing metal foil in close contact with the front of the carbon, and so conveying the heat away. The author has also referred to the difficulty of keeping the mica in between the commutator segments when each leaf of mica is not subject to tangential pressure. It occurs to me that the trouble of rising mica which is so frequently met with is due to this same reason, that is to say, when the mica sheets are built up all the flakes are not securely held, and heat combined with centrifugal force causes some of the mica to rise above the surface of the commutator.

Mr. Clough. Mr. F. H. CLOUGH: I do not think the author gives to the question of the critical speed of the shaft quite as much attention as it deserves. He does not make it quite clear whether he considers it possible to operate beyond the critical speed of the shaft, or whether it is necessary to keep the normal speed in all cases below this value. The sketches seem to indicate that every attempt is made to make the shaft as stiff as possible, and so, presumably, to avoid the critical speed, and yet the author in several places speaks of the effects which occur when passing through this critical speed. I would ask the author in his reply to touch on this point more fully than he has done in his paper. If it is dangerous and undesirable to pass through the critical speed, then I agree with his conclusions to the effect that it is necessary to keep the lengths between the bearings as short as possible and to use butterfly connections for the armature winding; but if, on the other hand, it is possible to pass through the critical speed with safety, then it would seem desirable to make the shaft smaller than indicated on his drawing, and so have the running speed well beyond this critical value, and in this way avoid such difficulties as are mentioned at the bottom of page 133, and be able to mount the commutator on a separate sleeve rather than mount it directly on the shaft. If the normal speed is well removed from the critical speed, it is not

* *Journal of the Institution of Electrical Engineers*, vol. 45, p. 494, 1910.

necessary to determine this latter value with great accuracy, and an approximate calculation is a comparatively simple matter. If, on the other hand, the critical speed is only slightly beyond the running speed, it is necessary to determine it with considerable accuracy, and the calculation then becomes complicated and difficult. In one place the author speaks of a second critical speed. I do not think, however, that this actually occurs. A second critical speed would be caused by the shaft taking an S shape, and would be associated with an oscillation of the armature about an axis at right angles to the axis of rotation; this would give a value far beyond the possible operating speed of the machine. Vibrations may occur, of course, beyond the critical speed, but these are probably due to the movement of some part of the armature causing a lack of balance, and are not, strictly speaking, a second critical speed. At the bottom of page 135, paragraph (*b*), the author makes the statement that whereas the shaft may be deflected when the armature is standing still, it will tend to strengthen out when the machine is running. I think he is in error here, as the gravitational forces will still have to be opposed by elastic forces in the shaft, which will cause deflection in the shaft whether the machine is rotating or not. In the latter part of the author's paper he puts forward a rather novel theory and method of calculation of a cylindrical shrink-ring commutator. Apparently the basis of his assumption seems to be that there shall always be a circumferential force between the segments of the commutator to keep the mica in place. However, I venture to suggest that it is possible to take a much simpler view of this problem and calculate the stresses primarily from the point of view of the centrifugal force, and to prevent the mica from becoming displaced by making it slightly wedge-shaped or by suitably roughening the commutator bars. This roughening may conveniently take the form of longitudinal grooves cut in the commutator bars, the first of which is so situated that it forms an indication when the commutator has been turned down to a safe limit. The shrinking of the mica under the effect of heat would seem to introduce an unknown factor which would upset the whole theory as advanced by the author, and, further, the probability is that the first time the commutator is run up to full speed and made hot the centrifugal and expansion stresses are such as to cause slight permanent expansion in the retaining rings with the result that when the commutator is again cooled down the initial circumferential force between the bars practically disappears entirely. Mr. Clough.

Mr. F. H. WYSALL: I have had some experience of two small direct-current turbo-generators during the last few years. The commutators have been spoken of most I think, and they certainly give us most reason for consideration. The tendency of the mica to rise has been got over by reducing it slightly below the surface of the commutator segments—a very simple thing to do, but one which has proved very satisfactory. The turbo-generators that we have in use at Dickinson Street are run all day—every day pretty well—and we have Mr. Wysall.

Mr. Wysall.

no trouble at all. The general design follows that recommended by the author, and we have four ring commutators, self-ventilated. The only differences I can think of are in connection with the disposal of the equaliser rings. They are in the position recommended by Mr. Livingstone, and the turbo-generators have end shields. The machines at Dickinson Street are very successful in operation, and I think it is only fair to say that their success is largely due to Mr. Hoult, who has given to you the main mechanical details of these machines. He was for a long time experimenting, and it was only due to his perseverance and extraordinary patience that direct-current turbo-generators at that time were of any use at all.

Mr. Barbour.

Mr. R. H. Barbour (*communicated*): The author has written a very instructive and thorough paper, which, however, bristles with the words "difficulties," "problems," and "troubles." It is pleasing to find him believing, in spite of all, that direct-current turbo-generators can be made reliable, but it is at least doubtful whether the mediocre performance of commutator turbos in the past has been due so much to inadequate comprehension of the mechanical difficulties as to the actual magnitude of those difficulties, however warily tackled. That complicated piece of mechanism, the commutator, is by its very nature unsuited to high peripheral speeds. Its component parts have just the shape which gives them the minimum of resistance to centrifugal force. It should not be forgotten that in a machine having, say, 60 commutator segments, and running at 3,000 revs. per minute, each brush has to change from one segment to another 3,000 times in every second. Centrifugal force is continually doing its best to produce unevenness in the height of each one of the 60 segments, and the moment one of them shifts, be it even $\frac{1}{1000}$ of an inch, the harm is done. These considerations render imperative the use of commutators of small diameter, and consequently of great length. Unfortunately, this adds to the difficulty of making a mechanically sound job, and incidentally necessitates a long thin shaft, letting in a host of vibration troubles. The author is quite right in wishing to see a shorter distance between bearings, but his proposals for accomplishing this by higher brush pressures, higher current densities, and higher peripheral speeds are open to grave objection. Apart from the mechanical difficulties, every one of these suggestions means an increase of the losses per square inch of brush contact surface, whereas these losses are already as high as the brushes will stand. With an ordinary carbon brush worked at 40 amperes per square inch the electrical loss in the contact is about 40 watts, and the mechanical loss in slow-speed machines may be another 80 watts, so that 120 watts at most are being turned into heat actually in the contact surface. At high speeds the friction loss is far greater, and may be as taken at least 200 watts per square inch, so that in the present turbine machines at least 240 watts are turned into heat in the contact surface—this is already double what is found best in slow-speed machines, and any further increase is likely to aggravate the present troubles. If a satisfactory solution is to be found, some

radical change in design must be effected. This the homopolar principle offers. Mr. Barbour.

In the homopolar generator commutation difficulties are entirely eliminated. The mechanical construction is immensely simplified, for slip-rings, if once set true, have no tendency whatever to take up eccentric positions. Even if they are assembled slightly out of truth the forces set up are negligible. Instead of a long thin shaft, a short one may be used, and its effective diameter increased to one-third of its length by pressing on a solid steel core; or the core and shaft may be made in one forging. Whilst efficient ventilation of a long commutator is impossible, that of a number of slip-rings is easy; the use of slip-rings, moreover, enables more efficient brushes to be used. The cost is reduced by the absence of interpoles and of compensating windings; there is thus not only a saving of copper, but also of labour. Finally, the speeds permissible are double those of commutator machines, so that, for a given steam consumption, the cost of the steam turbine is reduced 50 per cent.

Mr. R. ROBERTS (*in reply*): The mechanical design of electrical machinery contains a great deal of what might be termed the "personal factor," the variability of which may account for the many different opinions and criticisms called forth in this very interesting discussion. I quite agree with several speakers that the "common defects" are not all that are met with. Oil throwing is also common, but this question appears to be more in the province of the turbine designer, since the bearings are usually supplied by the turbine builder. Oil glands, or rather oil and air glands, as mentioned by Mr. Livingstone, are the only certain remedy I have met. The fan efficiency used in calculating the table on page 131 was 25 per cent., and the scheme sketched in Fig. 5 was designed to eliminate as far as possible all fan action. The sizes of air-cooling plants given by Mr. Catterson-Smith seem rather large; and hence it seems doubtful that, if of these sizes, a cooling plant would be preferable to the ordinarily used dust screens. The question of first cost and running costs, I fear, would also militate against the use of a refrigerating plant. The scheme suggested by Mr. Hoult has many points in its favour, such as thorough cooling and dust elimination; but, when starting up a cold machine, is there not a possibility that water from the damp cooling air would be condensed in the generator? Regarding the calculation of the critical speed of the shaft, the method I had in mind was that of Professor Morley as mentioned by Mr. Harrison, and is a method that is generally well known amongst designers. The method of Professor Stodola as given by Mr. Catterson-Smith is certainly good, but I think that of Professor Morley will appeal most to engineers as being more direct. To design the shaft and core so that the diametrical strains are equal, it is necessary to have a fluted shaft, and to design the core so that the stress at inner periphery is kept down to the desired limit. I congratulate Mr. Livingstone that he has not experienced a moving core—an accident that is very trying to the balancer. Mr. Roberts.

Mr. Roberts.

In answer to Mr. Clough's remarks, the chief defect of a critical speed (the second critical speed does not usually occur in an electrical machine) is the excessive vibration that usually accompanies it, which has a great influence in provoking instability of balance. Provided the design permits it, I should certainly run the machine below the critical speed. As the vibrations that accompany the critical speed are felt about 20 per cent. above and below the actual critical speed, it is preferable to design the shaft so that the critical speed is 50 to 60 per cent. of the running speed. My remarks *re* balancing were deduced from my own experience; perhaps I had not properly assimilated the main features of balancing before I began. In balancing a machine, I would first balance on middle ring to obtain good balance at that point so as to run up to full speed; then balance at the ends, at same time making compensating adjustments at middle ring. The use of either wire bands or solid rings, to take up the centrifugal forces of the windings, seems to be a matter of personal experience and prejudice. I have found machines retain their balance better with wire bands, provided always that these have been properly put on. I agree with Mr. Livingstone that soldering anneals the wire; it was for this reason that I wished the ends held mechanically. With regard to the effect of a burst, I have stood close to a machine when a wire band did burst without being hurt in the least; this machine was, of course, totally enclosed. Although no evidence is usually left after a burst as to what actually caused it, I am inclined to think that an earth or short circuit was nearly always the primary cause. It is doubtful if turbos are built nowadays without equalisers—in fact, for the reasons pointed out in the paper, it is too much to expect a machine to run well without them. Soldered joints, if well done, do not of necessity get warm, that is, provided they are liberally designed.

In reply to Mr. Everest, cleaning of air is not so important on direct-current machines because of the lower generating voltage, as there is no tendency for the current to jump across an air-space; but that because of exposed conductors the elimination of dirt would prevent a leakage arc forming. The 10-in. length of unsupported stator coil is merely arbitrary, because each unsupported length will have a natural frequency or critical speed; and if this frequency coincides with the frequency of revolution of machine, there is a great possibility that the coil will break. Mr. Clough is quite right—the object of the theory of construction of the commutator is to enable a commutator to be designed so that the possibility of mica rising between the commutator bars is entirely eliminated. His suggestion, however, of roughening the bars or of making the mica wedge-shaped is not sufficient, as from the flaky nature of the mica it will break up and fly out in pieces if there is no retaining tangential pressure. I agree that, in a badly designed commutator, there is a possibility of a permanent strain in rings after the first run; but this will not occur if full cognisance is taken of all the forces that occur in a commutator. Mr. Livingstone said that I had not mentioned the expansion stresses,

nor the proper integration of the initial, centrifugal, and expansion stresses. I did this because, apart from increasing very largely an already lengthy paper, I considered that he had already done this very fully in his book on commutators mentioned in the paper. The under-cutting of the mica mentioned by Mr. Whysall does not necessarily eliminate the trouble of the rising mica segments. Mr. Worrall's remarks regarding commutation were very interesting, as also is his very novel brush-holder. As sketched out, it is doubtful if it would commend itself to an engineer for use on turbos, but no doubt some modification in design could be made to retain the good qualities he claims and at the same time be suitable for a high-speed commutator where much vibration occurs. The curves for current collection given in Curve X were not put forward as possible figures to use on commutators, but rather as an indication that if such high values of current density and pressure could be used on slip-rings, higher values than those commonly used might be applied advantageously to commutators. It must, however, be borne in mind that before any theoretical or experimental data are applicable to a turbo-commutator, we must first have the surface running absolutely truly—a result which is difficult of attainment in practice. Mr. Barbour's remarks on the subject of the homopolar machine introduce quite a different view of the machine than the one discussed in the paper. It is doubtful if to some engineers slip-rings are preferable to a commutator. Perhaps we may look for the Utopian machine—a direct-current machine without slip-rings or commutator—before we can attain anything like perfection. Mr. Roberts.

Proceedings of the Five Hundred and Twenty-eighth Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, December 7, 1911—Mr. S. Z. DE FERRANTI, President, in the chair.

The minutes of the Ordinary General Meeting, held on November 23, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members:—

Joseph Horsnell May. | Henry Augustus Ratcliff.
Henry Bernard Stone.

From the class of Associates to that of Associate Members:—

Charles Henry Wm. Gerhardi.

From the class of Students to that of Associate Members:—

Peter Edward Bamford.
Reginald Gilray Barton.
Richard Arthur Broster.
Alec Whitworth Brydon.
Harry Church.
Walter John Cridge.
Frederick Habler Downie.
Harold Emmott.
Arthur Reginald Fraser.
Joseph Richard Hall.
John Hollingworth.
Stephen Holmes.
Rupert Colin Leslie.
Francis Walter Main.
Henry Walker H. Richards.
Joseph A. Rugeroni.
Claude Theodore Siebs.
William Duff Stewart.
Thomas Henry Varcoe.
Herbert Frank G. Woods.

Messrs. T. Stevens and F. N. Haward were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Members.

Travers John H. Blackley. | Gano Dunn.
Robert Stewart Whipple.

ELECTIONS—*continued.*

As Associate Members.

William Arundell.
Reginald Charles Atkinson.
Benjamin Joseph Beasley.
Pakenham William Beatty.
Bentley Emanuel Bolton.
George Edward Carr.
Hugh William Devey.
William Edmund Downey.
Reginald Henry Friend.
William Eden Highfield.
Herbert D. Johnston.
Edward Percy Jones.
John Ellis Jones.
Athelstan Joseph A. Kean.
Charles Balharrie Kinnes.
Silas Young Maling.
Ian Webb Massie.
Thomas Mills.
Rupert Douglas Moss.
Harold William S. Outram.
Alfred John Percival.
Walter Pleasance.
Evan Bertram C. Preston.
James Smith A. Primrose.
Ernest Melsom Redfern.
Glynn Salter.
John Henry Schnauber.
Harry Smith.
John Sykes.
Hugh Alister Tulloch.
Donald G. Vincent.
Denzil Brudenell Webbe.
William Wilson, B.E.
Johnstone Wright.

As Associates.

Ernest James Dutch.
Henry Charlton Houghton.
William Watson Howie.

As Students.

Godfrey Arblaster.
John Oliver Archer.
Edwin George Batt.
Francis Arkle Broadhurst.
John Palmer Castle.
Harold Norman Davis.
Spencer William Dunn.
Albert English.
Monindra Nath Ghose.
Harry Gibbs.
Allan Grad.
Walter Herbert Harris.
Alberto Villanueva y Labayen.
Alec Sacré.
Charles Emmanuel W. Smith.
Edward Morrison Teare.
Basil Percival K. Walsh.

The PRESIDENT: In connection with the proposed new Articles of Association I have to announce that since the last informal meeting the Council have taken further steps to ascertain the views of the members regarding the revised Articles of Association. They have received a number of suggestions which are being carefully considered to see how far it is possible to reconcile the different views and to embody them in the revised Articles. The time required to give these suggestions adequate consideration renders it impossible to make any further suggestion until early next year.

The following paper was read and discussed: "Notes on National and International Standards for Electrical Machinery," by Dr. Robert Pohl (see p. 174).

NOTES ON NATIONAL AND INTERNATIONAL STANDARDS FOR ELECTRICAL MACHINERY.

By Dr. ROBERT POHL, Member.

(*Paper received September* 4, 1911; *read before* THE INSTITUTION, *December* 7, 1911, *and before the* YORKSHIRE LOCAL SECTION *on December* 6, 1911.)

SUMMARY.

Introduction.

The "British Standards for Electrical Machinery" were issued by the Engineering Standards Committee in August, 1907 (Report No. 36). Their main provisions are identical with those contained in the Interim Report (No. 17) published in 1904. This first step in the direction of standardisation was necessarily of a tentative nature. It was so, unfortunately, to such an extent that it exerted but little influence.

It will be further admitted that in an industry progressing so rapidly as the manufacture of electrical machines, standard rules, even if quite satisfactory at the date of issue, will not remain so for more than a few years. Under these circumstances it is natural that criticism of the present rules and suggestions for a decisive advance in the direction of standardisation should have lately become more frequent. The desired revision has possibly been deferred in view of the deliberations of the International Electrotechnical Commission, which, in addition to its valuable work on nomenclature and industrial definitions, is turning its attention to the rating of machines. No doubt the ideal solution of the problems involved would consist in the framing, and, what is more difficult to achieve, the adoption of international rules for rating and testing.

It is gratifying to note the hopeful view which the President of the International Commission expresses with regard to this question. He states, "In many particulars the countries are already in such substantial agreement that the anticipated difficulties are much less than might at first appear."* Nevertheless, there are as yet some striking differences, to some of which attention will be drawn in this paper, and progress is bound to be slow. Moreover, there is the important problem of standardising outputs and speeds, which would offer the greatest difficulties to international settlement, and which has already been approached by the British Standards of 1907. Further progress in this direction is highly desirable and urgent, and for this reason alone, if for no other, it would appear unjustifiable to delay the promised revision of the British Standards because of the international deliberations.

I am well aware that the subject of this paper is essentially one for the careful consideration of a small committee of experts. Yet the widest possible expression of views is not only bound to be of considerable help in framing new standards, but it will also facilitate their general adoption. It is for these reasons, and in response to a request by the Chairman of the Yorkshire Local Section, that I venture to bring this subject forward for discussion. I wish to refer to Mr. Churton's Presidential Address as an expression of the need for revision and development of the British Standards.

Scope and Importance of Standards.

The scope of standards on electrical machinery may be said to be (1) the classification of machines with definitions of the technical terms

* International Electrotechnical Commission, "Rating of Electrical Machinery," August, 1911.

employed in such classification; (2) the specification of the performance to be expected from each class; (3) the formulation of definite testing methods to be adopted in ascertaining the performance; (4) the fixing of a limited number of standard voltages, frequencies, outputs, and speeds.

In so far as such standards tend to the production of high-class machinery and to the avoidance of disputes between contracting parties, they are of inestimable benefit to the community, as users of machinery, as well as to the whole electrical industry. Further, if generally adopted, they must prove of immense value to the manufacturer. They would enable him thoroughly to standardise his machines with consequent appreciable reduction in the cost of manufacture. The latter point can hardly be over-emphasised, and the degree in which this object has been attained by any national standards may be taken as a measure of their success or failure. Judging from this point of view, the British Standards of 1904 to 1907, in contrast to the German "Normalien," can only be termed a complete failure.

The following are probably the main reasons for this. In the first place, the British Standards are not comprehensive, many points of prime importance not having been touched upon. Secondly, and this is an important fact, they have practically remained a dead letter, because not many engineers even know of their existence, and very few indeed are conversant with their provisions. Reference to the standards, so far from being the rule, is an extremely rare occurrence Obviously, the mere formulation by a committee, however representative and influential, of standards and the issue of these in print are under the existing conditions of the electrical industry not sufficient to make the standards effective. To this end they must be brought forcibly to the notice, not only of the manufacturer, but of the buyer and user of machines. They should be fully discussed by this Institution, preferably in all its sections, before their final adoption.

A further help would consist in the issue of a cheap and handy pocket edition for quick reference which this Institution might supply free to all its members. It would further be essential to secure adoption by the leading insurance companies and the Government Departments as far as possible.

If these and other suitable steps were taken to force the attention of all concerned upon the standards, I feel convinced that an immediate change would come over our industry.

It has frequently been pointed out how severely British manufacturers are handicapped by having to build so large a proportion of their machines to special conditions, although in the majority of these cases standard machines would serve the requirements at least equally well. So long as this continues, manufacture in really large quantities, with consequent reduction of labour and standing charges, as well as improved delivery, will remain impossible even to the largest firms. The result is that competition with Continental firms not similarly handicapped in their home market is only possible at

unremunerative prices. In the numerous attempts to explain the striking prosperity of the large German firms as compared with the corresponding British industry, this most important point has usually been lost sight of. Due to the existence of generally accepted rules, and to the fact that the consumer is accustomed to adjust his plant so as to suit the manufacturer's standard outputs and speeds, the German firms can produce standard machines in large quantities by piece-work methods and sell them from stock. On the other hand, generally speaking, British firms manufacture individual machines in the absence of accepted standards, and competition forces them to quote to almost any specification and for any desired output and speed. Perhaps the most notable example of the admirable and highly beneficial work of the Engineering Standards Committee is the standardisation of sections for structural steel. This has been computed to have resulted in a saving of at least one million pounds per annum. Though the direct and immediate saving to be effected by standardising electrical machines may not be so great, the possible advantages to be derived, if they were expressible in figures, may be valued much higher, considering that they may mean the transformation of a weak and stagnant industry into a healthy and progressive one. This view cannot be seriously affected by the wave of comparative prosperity through which most electrical firms are now passing.

It might be objected, however, that complete standardisation will be a hindrance to the introduction of improvements, and thus interfere with the process of natural development. But the standardisation of steel sections has in no way interfered with progress in manufacturing methods, and such apprehension concerning the electrical industry is similarly unfounded, so long as we confine ourselves to the fixing of standard outputs and performances, and refrain from the unfortunate and only slowly dying practice of specifying the methods by which the desired results are to be obtained. So long as the choice of ways and means is left to the discretion of the specialist, the path is free both to advancement in detail and to entirely new methods.

The following notes do not represent an attempt to cover the ground comprehensively, but only deal with chief points likely to form the subject of a profitable discussion. It was therefore thought advisable not to adhere to the systematic division into the four main sections suggested above, but to follow generally the order chosen for the British Standards of 1907, excepting the portions dealing with standard outputs and speeds, which, jointly with the question of pressures and frequencies, are left over to the end.

I. Rating.

Two methods of working are recognised by the Committee, viz. :—

(A) Continuous working.
(B) Intermittent working.

A third, "short-period working," is recognised by the German and

Belgian Standards. It is distinguished from "intermittent working" in that the period of running is too short to allow of the final temperature being attained, but is succeeded by a period of rest long enough to allow of the temperature falling again to practically that of the atmosphere. As this class of machine is of very rare occurrence in practice, however, it is probably wise to abstain from complicating the rules by its introduction. The same remark applies to the American "minute rating." The object aimed at by these ratings will be better attained if a subdivision of "intermittent working" were adopted by deciding upon three standard degrees of intermittency, as suggested later on.

The definitions adopted for both (A) and (B) are open to criticism.

(A) *Continuous Working.*—A machine for continuous working is defined as one which can work continuously for 6 hours and conform to the prescribed tests, but this rating, as stated in a footnote, is not intended to apply to machines which have to run from week-end to week-end without a stop. This latter reservation and the restriction to a 6-hours' run are in my view unnecessary and only calculated to cause uneasiness. Modern machines, excepting those of very large size and static machinery, attain their final temperature practically within 6 hours. There is thus no reason why a machine capable of running for this length of time should not be suitable for running from week-end to week-end, always provided that the bearings, brush-gear, etc., receive proper attention.

I should suggest that the words "for 6 hours" be eliminated and that the following definition be adopted: "The output of machines for continuous working shall be the output at which, with suitable attention, they can work continuously from week-end to week-end. Their suitability for this shall be proved by their passing the prescribed tests."

(B) *Intermittent Working.*—When framing the definition of intermittent working, the Committee were aware that the 1-hour test used for this definition did not meet the requirements of the industry.

This clause was stated to be under revision at the time of issue in 1907. So far as I am aware, however, no alteration has since been made. This question as to the most suitable method of rating and testing intermittently working machines has been repeatedly discussed during the last few years. There is a consensus of opinion as to the unsuitability of the present rules relating to them.

It is recognised that in the majority of cases the 1-hour rating leads to unnecessarily large motors, that the principle of short-time tests is wrong, that the rating should depend on the load factor, and that suitable tests to conform with the specified load factor ought to be adopted. (I have made definite suggestions in a recent paper,* to which I wish to refer.)

The following definition may be submitted: "The output of motors for intermittent working shall be the output at which, with suitable

* *Journal of the Institution of Electrical Engineers*, vol. 45, p. 216, 1910.

attention, they can work from week-end to week-end intermittently with the specified load factor. Their suitability for this shall be proved by their passing the prescribed tests." A definition of the term "load factor" is required.

I further suggest that only three standard load factors be adopted —namely, $\frac{1}{2}$, $\frac{1}{4}$, and $\frac{1}{6}$. The load factor $\frac{1}{2}$ is generally applicable to motors for lifts and for severe crane and hoist work; $\frac{1}{4}$ for ordinary shop cranes (lifting and travelling), etc.; $\frac{1}{6}$ for traversing and other light duty.

II. Name-plates.

The present instructions under this heading appear to be quite satisfactory, and an addition would only be required in the event of a definition for intermittently working machines similar to the above suggested one being adopted. In this case the name-plate of such machines should state the load factor.

III. Classification.

The present standards give the classification of motors with reference to the degree of protection under four headings—*i.e.*, open, protected, ventilated, and totally enclosed. This classification should apply to machines generally, and not merely to motors, inasmuch as the first three classes, at any rate, are used for generators and converters as well as for motors.

The development of the last few years have made it necessary to extend the list by the addition of flame-proof enclosed machines as used for mining purposes. A flame-proof enclosed machine may be defined as one in which all live parts are enclosed in a casing or casings, so designed as to withstand the effects of an internal explosion and to prevent the transmission of the latter to an outside explosive atmosphere. This definition would comprise the two known classes of flame-proof motors, the non-ventilated or long-joint type, and the ventilated or grid type. In addition to the ordinary tests of totally enclosed machines, flame-proof motors should in all cases be subjected to stringent explosion tests. The details of these require careful consideration in collaboration with mining experts.

IV. Wearing Depth of Commutators.

The recommendations under this heading, as reprinted in Table II., especially those for the larger diameters, go considerably beyond what corresponds to good modern practice. A wearing depth of $1\frac{1}{2}$ in., for instance, is justifiable only on the assumption that the corresponding commutator will require grinding up or turning some thirty to forty times during the useful life of the machine. Such a provision was hardly necessary even in the days of copper brushes and glass paper. The advent of carbon brushes and commutating poles, coupled with improvements in the mechanical design of commutators, have

resulted in the fact that turning or grinding, except perhaps shortly after erection, has become altogether unnecessary. The commutators of modern machines should form a hard, shining surface, which should not even be touched with emery cloth except very occasionally. For these reasons leading consulting engineers and insurance companies specify as a rule much smaller figures than those of the above table. A revision of the latter is desirable, not only in the interest of the manufacturer exposed to international competition, but also in order to save the purchaser useless expense. This is a subject essentially suitable for the consideration of the International Electrotechnical Commission, seeing that, so far as my knowledge goes, no other

TABLE II.

Commutator Diameter.	Radial Wearing Depth.
Inches.	Inches.
0–4	$\frac{3}{8}$
4–6	$\frac{1}{2}$
6–9	$\frac{5}{8}$
9–12	$\frac{3}{4}$
12–18	1
18–24	$1\frac{1}{4}$
Above 24	$1\frac{1}{2}$

country has as yet adopted standards for the wearing depth of commutators.

V. PERFORMANCE.

Perhaps the most important points of any standard specification, those dealing with the running qualities, have only been touched upon by the present standards, so far as temperature rise is concerned. We have to consider (A) Sparklessness, (B) Overload capacity, (C) Voltage regulation, (D) Efficiency and power factor, (E) Insulation, and (F) Temperature rise.

(A) SPARKLESSNESS.

Ruling British practice requires stringent conditions on this point. I suggest the following clause: "There shall be practically no sparking at the brushes of commutators or slip-rings at any load up to and including full load, and no injurious sparking at the specified overloads, and the position of the brushes, except where otherwise stated, shall remain fixed for all loads."

There is no difficulty in complying with these conditions in modern machinery, and the corresponding clauses in the French, Belgian, and German Standards appear to be unduly lenient. The latter state that machines must run so sparklessly at all loads that an application of glass paper or the like is only necessary after at most 24 hours' running. They also limit the outputs for which the brush position is to remain unaltered to the range from $\frac{1}{4}$ load to full load.

(B) Overload Capacity.

Here, again, we find a very striking discrepancy between average British practice, which has adopted very large factors of safety, and the French, Belgian, and German Standards. The latter specify the following overload capacity :—

Generators ... ... Motors ... ... Rotary converters	25 per cent. for $\frac{1}{2}$ hour,
Motors ... ... Rotary converters ... ... Transformers	40 per cent. for 3 minutes,

whilst, according to the French and Belgian rules, it is 20 per cent. for a period equal to $\frac{1}{10}$ and $\frac{1}{5}$ respectively of the full-load run. On the other hand, British specifications generally ask for an overload capacity of 25 per cent. for 2 hours, 50 per cent. for $\frac{1}{2}$ hour, and the standard machines of good makers will stand up to this without difficulty.

Judged from this point of view only, they are on an average 20 per cent. larger in output than Continental machines made for the same nominal output and complying with the respective country's standard specification.

In view of the fact, which I shall prove later on, that modern well-ventilated machines reach their final temperature after a comparatively very short run, an overload of 2 hours' duration is, in my opinion, an unnecessarily severe test for small and medium sizes when following upon a continuous run. The principle adopted in France and Belgium of making the duration of the full-load run dependent on the time required for the machine to reach its steady temperature is theoretically correct ; yet, I doubt whether it would work well in practice. I suggest that 25 per cent. for 1 hour, 100 per cent. momentarily, be adopted for machines for continuous rating, and 25 per cent. for 5 minutes, 50 per cent. momentarily, for intermittently working machines. Generators should be capable of maintaining their full voltage up to 25 per cent. overload (15 per cent. in the German specification) when running at their full-load speed, the power factor in the case of alternating-current generators being equal to the normal power factor.

(C) Voltage Regulation.

The voltage regulation of any generator may be defined as the difference between the maximum and minimum pressure, stated as a percentage of the full-load pressure, which is obtained when gradually changing the load from full load to no load with constant speed and fixed position of regulators. In the case of direct-current shunt dynamos and of alternators there is a continual rise in pressure with decreasing load, and the regulation as above defined is identical with the percentage pressure rise, obtained when full load is thrown off, with constant speed and fixed position of regulators. In the case of compounded machines, however, the maximum pressure does not necessarily occur at no load, but may be found at any intermediate load, so that the wider definition given above is needed.

The present rules provide that the regulation of alternators shall not exceed 6 per cent. on a non-inductive load and 20 per cent. on an inductive load having a power factor of 0·8, and there appears to be no reason for departing from these figures, except in cases where a much larger pressure rise is permissible in view of the employment of quick-acting automatic regulators.

Generators compounded for constant pressure at all loads should maintain this pressure within 2 per cent., and the voltage of over-compounded generators, for a rise in pressure from no load to full load not exceeding 10 per cent. of the no-load pressure, should not depart at any load more than 3 per cent. from the ideal linear load characteristic.

(D) Efficiency and Power Factor.

A clause fixing the loads for which the efficiency and power factor should normally be stated, and subsequently tested, is desirable. Some specifications ask for these figures at $1\frac{1}{4}$, $\frac{1}{1}$, $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ load, others at $\frac{1}{1}$, $\frac{2}{3}$, $\frac{1}{3}$ load, the majority only at full load. For the characterisation of the efficiency and power-factor curves under ordinary conditions the full-load and half-load figures are, in my opinion, sufficient. A regulation is further desirable stating by which method the efficiency is to be ascertained. I suggest that the measurement of the individual losses be adopted as the standard test, where not otherwise agreed upon, in view of its simplicity and of the ease and accuracy with which it can be carried out under almost any commercial conditions. It is well known that the results obtained by this method are slightly too favourable, but the error may be largely compensated by adding to the I^2R losses of the armature or rotor windings an ample allowance for the loss in the brushes on commutator and slip-rings. For fixing the total drop, brushes might be divided into three classes, *i.e.* carbons, metal-carbons, and metal brushes. There should further be a list of standard minimum efficiencies and power factors in the tables of standard machines suggested later on.

(E) Insulation.

No hygroscopic materials such as cotton and paper should be employed in electric machines unless they are thoroughly impregnated either before or after winding. It is an open question whether the measurement of insulation resistance is of real value in addition to a flash test. With regard to the latter the rules should be kept as simple as possible. I suggest that all windings for working pressures above 200 volts be flashed to earth with alternating current of twice the working pressure, but not less than 1,500 volts; windings for less than 200 volts with 1,000-volt alternating current. The pressure should be raised gradually for this flash test and the full voltage be applied for 1 minute.

(F) Temperature Rise.

There is an extreme diversity of view as to the highest permissible temperature rise, which reflects itself in the specifications. The rise specified varies between limits as wide as 25 and 55° C. Frequently it is stated that "no part of the machine must rise more than 40° C.," and it is not unusual that the same limit is set for the rise after a run consisting of 6 hours on full load followed by 2 hours on 25 per cent. overload.

Seeing further that the permissible temperature is of paramount importance for the rating of machines, and that the present rules have proved unsatisfactory, a more extensive consideration of this subject will not be out of place.

1. *Highest Permissible Internal Temperature.*—The investigations of the National Physical Laboratory made on samples of cotton-covered wire * lead to the conclusion that cotton when exposed for prolonged periods to temperatures up to 125° C. (257° F.) undergoes no serious change. Above 125° C. it darkens in course of time, without, however, losing its insulating qualities, and even at 180° C. it proved an excellent insulator from the electrical point of view. Judging merely by change in colour, 125° C. (257° F.) is given as approximately the safe limit. It would probably be unwise to exceed this figure for extended periods, especially where non-impregnated cotton is present, because the change in colour is an indication of the well-known change in the mechanical properties of the fibre which "loses its nature," involving the danger of internal short circuits, more particularly in non-stationary coils. These experiments, however, were carried out with non-impregnated cotton, and are therefore not directly applicable. The coils of modern machines are vacuum-dried and pressure-impregnated in such a manner that the varnish completely permeates even heavy coils, and when dried the pores of the cotton throughout the coil are filled with a cohesive substance capable of withstanding a temperature higher than 125° C. The experiments of the National Physical Laboratory on the influence of temperature on insulating materials,† during which

* Engineering Standards Committee, Report No. 19, p. 19.
† *Journal of the Institution of Electrical Engineers*, vol. 34, p. 613, 1905.

impregnated and non-impregnated press-spahn, oilcloth, and similar materials were investigated, tends to confirm the view that impregnation reduces to a certain extent the deleterious effect of high temperatures on the mechanical properties. In view of the above, and of the rule suggested under "Insulation," that all hygroscopic insulating materials such as cotton must be thoroughly impregnated, I submit that we work with an ample margin of safety if we limit the highest internal temperature of field coils to 125° C. It must be kept in mind in this connection that the inner portions of field coils exposed to this temperature have only a very small potential difference between layers, and are tightly packed so that there can be no suggestion of severe mechanical or electrical stress. As a matter of fact, certain not uncommon types of field coils of modern machines, showing a surface rise of not more than 40 to 45° C., frequently possess internal temperatures much beyond 125° C. and no ill-effect is experienced.

For direct-current armatures and alternating-current stator and rotor windings a more conservative rating is desirable, in view of vibrations and high differences of pressure between layers. I suggest the rules should be framed in such a manner as to ensure that the highest internal temperature of distributed windings will in no part exceed 110° C. Before we can proceed to the consideration, on this basis, of the temperature above the surrounding air to be permitted as the result of specified tests, we must discuss the question as to the highest temperature of the atmosphere for which standard machines are intended to be suitable, the important problem as to the best methods of measuring the temperature, and lastly, the duration of tests.

2. *Highest Temperature of the Atmosphere permissible for Standard Machines.*—The British standards give this figure as 25° C. (77° F.), whereas the German rules are based on an air temperature of 35° C. as a maximum. I strongly urge that the same figure, *i.e.*, 35° C., be adopted as the basis for the British standards. This suggestion is made not so much with reference to the working conditions in this country—although the temperature in many British factories, and even in the central stations, is frequently in excess of 25° C.—but chiefly in order to meet the requirements of the export trade. If it is generally understood that standard machines are amply safe for any air temperature up to 35° C. (95° F.) a large proportion at any rate of export machinery need no longer be made to abnormal conditions relating to temperature rise, a point which is likely to benefit us appreciably in foreign markets.

3. *Methods of Measuring Temperature Rise.*—(A) *Field Coils.*

(*a*) *By External Thermometer.*—Average British practice, as distinguished from the "British Standards," permits a rise of 70° to 75° F., or about 40° C., as measured by thermometer on the surface of any stationary or moving coils. This is lower than required in the interest of safety where distributed windings are concerned, in which there is

only a small difference between the highest temperature in the interior of the coils and the surface temperature. It is justifiable, however, in the case of stationary field coils, in which the highest internal temperature rise may be anywhere from 1½ to 2½, and even 3½ times as high as the rise of the surface, the ratio depending chiefly on the depth of the coil, the amount of taping and covering of its surface, and the intensity of cooling. This uncertainty as to the relation of the maximum to the surface temperature was strikingly demonstrated by Mr. Rayner's experiments, carried out at the National Physical Laboratory. To judge from the results given in his Table II.,* one of the coils tested (No. 8), which was covered with ⅛ in. thickness of canvas, paper, and leatheroid, and also with string ⅛ in. thick, would possess a maximum internal temperature of at least 150° C., with a rise of the surface of only 40° C., whilst another coil (No. 9) wound on a metal former and without external covering would for the same rise of the surface be less than 75° C. inside.

Results such as these prove that the present practice of judging field coils from the temperature rise measured on the surface is not only unscientific but may be misleading to the point of danger. Indeed, this is generally becoming more serious with the employment of forced ventilation, which leads to an increase in the permissible loss per unit of surface, but must at the same time necessarily raise the internal temperature gradient.

There is another aspect to this problem. So long as through the character of the test the surface temperature is made of foremost importance there is little inducement for manufacturers to introduce methods of design and ventilation leading to a low temperature gradient inside the coil. In fact, the outer surface of coils is now frequently covered, not merely with thin taping, which affords a desirable protection for motor work, but with quite an excessive amount of canvas, presspahn, leatheroid, and string. This has a very decided effect on the internal temperature, but does not appreciably raise the temperature of the surface, and it may thus be done with impunity so long as surface measurements remain the ruling test. The difference in the methods of testing for temperature rise also explains the difference in the design of field coils of German and British machines. The former employ to a very large extent subdivided and ventilated coils, which are very rarely met with in this country.

(*b*) *By Resistance Method.*—In view of these or similar considerations the Engineering Standards Committee in 1907 followed the decision come to a few years previously by the German Institution, viz., that the temperature of field coils shall be measured by the resistance method. The increase in resistance indicates the mean instead of the surface temperature, and is therefore considered to approach more closely the all-important peak value.

The rule reads :—

"The measurement of the rise in temperature of stationary coils,

* *Journal of the Institution of Electrical Engineers*, vol. 34, p. 655, 1905.

and whenever practicable that of moving coils, shall be made by the resistance method.

"The rise in temperature is given by the following formula:—

$$\text{“Temperature rise in } ^\circ\text{C} = (238 + t)\left(\frac{\text{resistance hot}}{\text{resistance cold}} - 1\right);$$

"where $t =$ temperature in °C., at which the resistance cold is measured.

"The permissible temperature rise for stationary coils (by resistance) is 60° C. (108° F.)."

The German rules are similar, but while allowing 60° C. rise for cotton covering, they permit a rise of 70° C. for stationary coils of paper-insulated wire, and 90° C. for stationary coils of enamel or asbestos-covered wire in all cases measured by resistance method, they also consider these figures safe for a room temperature of 35° C., whereas the British Standards assume an air temperature not exceeding 25° C.

It must again be pointed out that the recommendations of the British Standards relating to temperature tests have made practically no impression on the British electrical industry.

The resistance method is not adopted in more than perhaps one case in a hundred, and where it is specified its spirit is frequently misunderstood, and a temperature rise of about 40° C., usual for surface measurements, is specified to be obtained by resistance method.

There is a twofold reason for this disappointing result. In the first place, no doubt the standards are not sufficiently known. Secondly, however, we are driven to the conclusion that the resistance method, simple as it is to the professional tester, is yet too cumbersome and complicated in its application for the average engineer. It also possesses inherent defects. As it requires the measurement of the resistance cold in addition to the warm resistance, definite conclusions cannot be obtained from the state of the machine at the end of the test only. Frequently where the resistance method is resorted to, it is found necessary for the inspecting engineer to return to the works a day after the official test for the verification of the resistance cold, because preliminary runs made it impossible to ascertain this with accuracy at the beginning of the test. It is a decided drawback of any test if it relies on the difference between two measurements taken under different conditions and at different times.

Finally, this important fact must not be lost sight of: The resistance method furnishes after all only the mean temperature of the whole field circuit, and takes no account of the discrepancies in the temperature of individual coils. The latter are sometimes very appreciable indeed, so much so that the rise of the surface of the coil in the top half of a slow-speed machine, measured by thermometer, is occasionally found to be higher than the mean rise of all coils found by the increase in resistance. Considering all these points, we are driven to the conclusion that the resistance method, in spite of its almost

universal official recommendation, represents by no means an ideal solution of the problem.

This reopens the search for a way of ascertaining the highest internal temperature of a coil with a reasonable degree of accuracy. To be suitable for commercial conditions any such method must be extremely simple and reliable, and must require no special instruments. This condition eliminates at once the well-known laboratory method involving the use of thermo-couples. It should, furthermore, give the internal temperature as directly as possible, and thus act as an inducement to study the design of field coils with a view to lowering not merely the surface but the internal temperature.

(*c*) *By Internal Thermometer.*—I submit that it is possible, without serious inconvenience to manufacturers, to provide for a direct measurement of the internal temperature by means of the thermometer. It is only necessary to this end to wind into the field coil at a

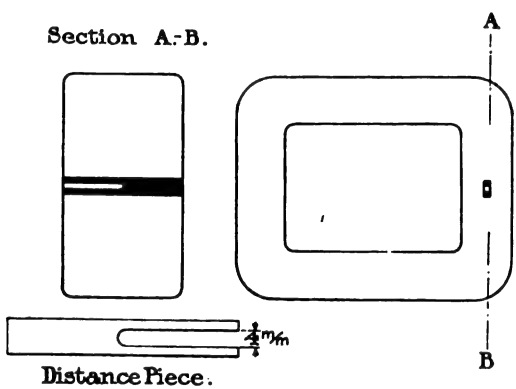


FIG. 1.

point where the maximum temperature may be expected a distance piece of wood or other insulating material enabling the subsequent insertion of a thermometer. Fig. 1 indicates the arrangement of the distance-piece for field coils. Insertion of the thermometer either from the top or from the bottom may be arranged for according to convenience. To receive a thermometer about 3 mm. thick, the distance-piece need only be 4 mm. wide, and would not add to any appreciable extent either to the external dimensions or to the cost of the coils. The objection might be raised that one cannot with certainty predict at which point the highest temperature is likely to occur, but I submit that the test will be sufficiently accurate for practical purposes, if we provide for the measurement of the temperature at or near the centre of gravity of the coil section at any convenient point of the circumference of the coil. The temperature curves for the interior of field coils are so flat in the neighbourhood of the peak that no serious error will be intro-

duced even if this point is not the theoretical maximum. This is clearly visible from the researches of the National Physical Laboratory, which further prove that there is practically no temperature gradient in the circumferential direction anywhere in the coils. Nevertheless, to be quite safe we can take the possibility of such errors into account by making a reasonable allowance for them in fixing the permissible temperature as measured in this manner. But such allowance need only be small, say 10° C., because we shall certainly get results much closer to the maximum than are obtainable by the resistance method. To prove this contention a series of tests was carried out on coils as shown in Fig. 1. The internal thermometer registered in all cases a temperature rise between 12 per cent. and 20 per cent. higher than was ascertained by resistance method. The curves in Fig. 2, which

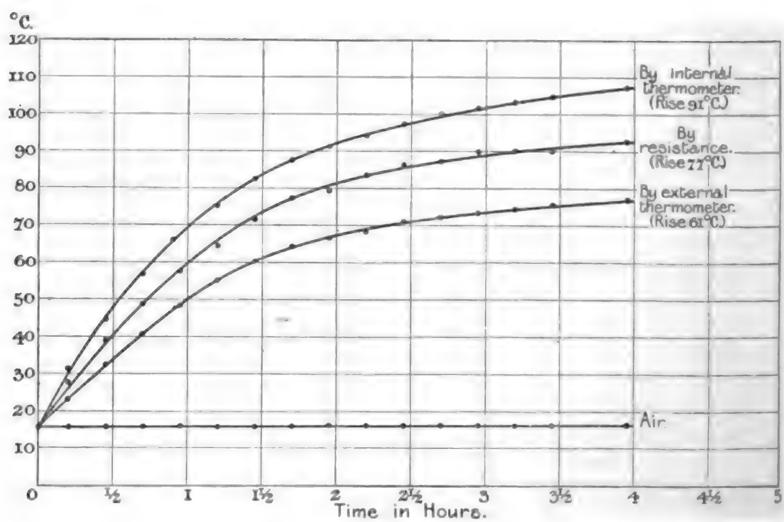


FIG. 2.

are self-explanatory, may serve as example. In the case of very small machines, below, say, 10 H.P., the depth of the coil is not so great as to justify provision for internal measurement, the temperature of the surface being a sufficient indication of its internal rise.

(B) *Distributed Windings.*

According to the present British Standards all stationary coils, which includes alternating current stator windings, must be tested by the resistance method. For rotating coils the rule applies that they shall be tested by resistance method whenever practicable, but "when it is not practicable to measure the resistance of a coil, the rise of temperature shall be ascertained by means of a thermometer or thermo-couple placed in contact with the coil or core, whichever

be the hotter." The permissible rise is given as 60° C. by resistance, 50° C. by thermometer or thermo-couple.

Whilst opinions may differ as to the suitability of the resistance method for field coils, there is likely to be general agreement with the contention that its employment is unnecessary in the case of all distributed windings. It is generally possible to find portions of such windings, the temperature of which, as measured by thermometer, is at least as high as the mean temperature of the whole winding measured by resistance method. This is due to the difference in temperature between the parts of the winding embedded in slots and those outside the core.

Furthermore, the resistances in question are mostly of a very low order, and whilst their accurate measurement may meet with no serious difficulty at the maker's works, it is mostly far from simple and frequently impracticable on site under ordinary conditions. No method of measuring the temperature rise can, however, be considered satisfactory which is not capable of easy application on site and under ordinary working conditions, as well as in the testing department of the manufacturer. The resistance method is also evidently unsuitable for windings in which equalising connections are employed, as it will give no indication of the temperature to which the latter will rise.

Under these circumstances there appears to be no justification for retaining the resistance method for distributed windings, the simple thermometer test being preferable from all points of view.

4. *Duration of Temperature Tests.*—The present rules provide for a 6-hour test for all rotating machines irrespective of size. It is well known, however, that very small machines may reach their final temperature within less than 1 hour, whilst large slow-speed generators and alternators require sometimes more than 10 hours to reach a settled state. Manufacturers should not be compelled to run small motors for quite unnecessarily long periods. On the other hand, purchasers of heavy plant cannot be expected to be satisfied with a run of only 6 hours. The solution of this difficulty seems to lie in the adoption of a rule similar in principle to that at present in force for the testing of transformers, which reads: "They shall be run on load for a period sufficiently long to enable the transformer to attain such a temperature that the increase of temperature does not exceed 1° C. per hour." If a similar rule were employed for rotating machinery the duration of the run would correctly depend on the time constant T of the machine, *i.e.*, on the ratio $\frac{\text{watt-hours stored per degree temperature rise.}}{\text{watts dissipated per degree temperature rise}}$ I submit, however, that one gets near enough the final temperature rise in modern rotating machines if the temperature at the end of the run is still rising at the rate of 1° C. during the half hour, and that for 1° C. in 1 hour the duration of the test is longer than needed. To prove this I have plotted in Fig. 3, curves C and D, the duration of the test for both 1° rise during the last hour and 1° rise during the last half hour. Curves A and B indicate the respective errors introduced

by not continuing the tests indefinitely. The curves are plotted as a function of the time constant T. Fig. 4 shows the time constants for a series of modern protected-type motors up to 250 H.P. It will

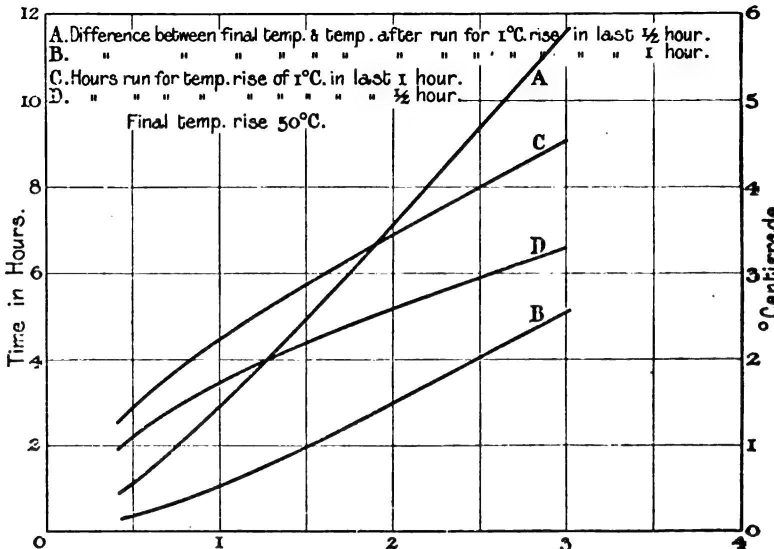


FIG. 3.

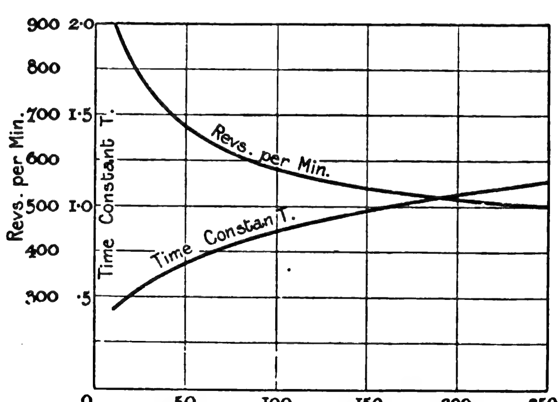


FIG. 4.

be found that the largest of these machines has a time constant of only 1·15.

The time necessary to reduce the gradient of the temperature curve

to 1° C. rise during the last half hour is 3¾ hours, and the difference between the temperature attained and the final is less than 2° C. for a final rise of 50° C.

By making an allowance of, say, 5° C. to cover this difference, we should therefore be quite safe in stipulating the length of the run on the suggested basis of 1° C. rise, *i.e.*, 2 per cent. increase in temperature rise, during the last half hour of the run, even for very large machines.

If we continued to run the above 250-H.P. motor until the rise was only 1° C. during the last hour, the total duration of the test would be about 5 hours, but the further rise during the additional 1¼ hours would only be about 1° C., which is well within the accuracy of such tests.

The curve, Fig. 5, giving the time required for well-ventilated machines to approach their final temperature, will perhaps be sur-

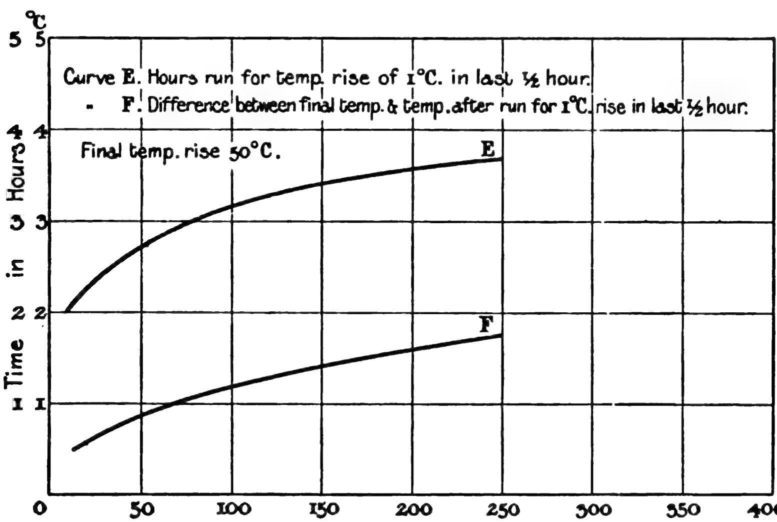


FIG. 5. Horse-Power of Protected Type Motor.

prising to those not in intimate contact with modern developments. It appears that under the suggested rule a 10-H.P. protected-type motor need only be tested for 2 hours, a 50-H.P. protected-type motor for 2¾ hours, and the error introduced by reducing the testing period to these low figures is less than 1° C. in both cases. Summarising, I suggest the following rule: The duration of the full-load test shall be such that the temperature rise shall not increase by more than 2 per cent. during the last half hour of the run. In order to ascertain this, a thermometer fixed to a suitable stationary part of the machine shall be employed.

As the duration for the test of very small machines would obviously become exceedingly short, it might perhaps be advisable to fix a minimum length of test of 2 hours.

The foregoing considerations will now enable us to make definite suggestions on the last point.

5. *The Permissible Temperature Rise, as ascertained by the Specified Tests.*—This must be such as to ensure that in the interior of field coils the actual temperature of 125° C., and in distributed windings 110° C., is not exceeded. The highest rise must, in consequence, not exceed $125 - 35 = 90°$ C. and $110 - 35 = 75°$ C. respectively. For distributed windings, such as direct-current armatures, alternating-current stator and rotor coils, which must be measured by thermometer on the surface, an allowance must be made for the temperature drop in the outer insulation and in the interior of the coil. The sum of these is not likely to exceed 20° C. In addition we are to allow 5° C. to meet the discrepancy due to reducing the durations of the test, or a total of 25° C., leaving a rise of 50° C. In the case of field coils for direct-current machines and alternators if measured by internal thermometer the margin to be allowed consists of 10° C. possible error due to the thermometer not being placed at the point of highest temperature, and 5° C. on account of the reduced length of run, leaving a rise of 75° C. This is, in my view, a much safer specification than the usual one of 40° C. rise measured at the surface, and also safer than the present recommendation of 60° C. measured by resistance method.

Special Heat-resisting Materials.—Where special materials designed to resist high temperatures are employed a much higher temperature rise is rightly permitted by the present standards, but the exact amount is left to agreement. The development of such well-known materials as asbestos and enamel-covered wires, which are bound to become of great importance, might well be encouraged by allowing definite higher figures where they are employed.

Single-layer Windings of heavy copper strip, wound on edge, as largely employed for commutating poles, and sometimes for alternator coils, would also be quite safe if one allowed a temperature rise of 75° C. as measured by thermometer on the surface, seeing that such coils possess an almost uniform temperature throughout.

Squirrel-cage Rotors.—There need further be no limit to the temperature of squirrel-cage rotors, unless ordinary soldered joints are employed, for which the approximate limit of safety is a temperature of 150° C.

VI. Standardisation of Pressures and Frequencies, Outputs, and Speeds.

The last and from the manufacturer's point of view probably most important problem, is the standardisation of outputs and speeds which must be considered in conjunction with the fixing of standard pressures and frequencies.

(A) Pressures and Frequencies.

The resolutions adopted by the British Standards Committee fix the standard low pressures for direct- and alternating-current generators

at 115, 230, 460, 525 volts, for motors at 110, 220, 440, 500 volts, the high pressures at 2,200, 3,300, 6,600, 11,000 volts, and 2,000, 3,000, 6,000, and 10,000 respectively.

In view of recent developments, and in order to simplify the standardisation of machines, it would be advisable to delete 115 and 110 volts, retaining this voltage only for exciters. The provision for 115/110-volt armatures in a series of standard direct-current machines leads to many difficulties due to the great length of the commutator. Happily this pressure continues to be employed only in a few small private plants, its adoption for new installations is justifiable only in rare cases, and generally speaking it should be discouraged. I also suggest the replacement of 525 and 500 volts by 580 and 550 volts respectively, which are at least equally common pressures, and preferable in the interest of easy standardisation, as will be seen later on.

The standard frequency for alternating-current work is 50 cycles, but "exception is made where the circumstances demand a lower frequency, in which case a standard of 25 periods per second shall be adopted." It may be questioned whether the latter recommendation, of 25 cycles, is still justified.

Some public supply authorities adopted this frequency at a time when 50-cycle rotary converters were as yet of doubtful reliability, and the above recommendation was probably influenced by similar considerations. For ordinary industrial purposes a 25-cycle supply has important disadvantages, and its adoption renders the standardisation of machinery appreciably more difficult. Cognisance might be taken of the fact, however, that the frequency of 40 cycles has been largely adopted for private installations, and that it is the standard frequency of some of the largest supply authorities in the country. It possesses the important distinction that it is approximately the lowest periodicity at which metal filament lamps may be employed without discernible flicker, and it leads to higher power factors compared with 50-cycle circuits, especially where slow-speed machinery has to be installed.

From the manufacturer's point of view the provision for 40-cycle machines in connection with a system of standard 50-cycle motors and alternators would meet with no serious difficulty.

(B) Outputs and Speeds.

The British Standards Committee took a very important and bold step in deciding upon a series of normal outputs and speeds for direct-current and alternating-current generators up to 1,000 k.w. and for motors up to 100 H.P. That there are no such standards in the German "Normalien" is probably accounted for by the process of concentration in the German electrical industry, from which emerged a very small number of large firms strong enough to enforce their own standard outputs.

The tables for direct-current and alternating-current motors given in the standards of 1907 unfortunately contain only one speed for each

standard output, and the output steps are further too big. These lists fail to satisfy the greatly varying requirements of the user. To meet practical needs with the smallest possible number of frames and windings modern methods of standardisation must be employed in drawing up the output tables. It is particularly essential that for every standard output there should be a reasonable number of standard speeds arranged with approximately uniform steps.

1. *Direct-current Motors.*—The columns 1 and 2 of the following table represent the present recommendations, and their defects will be seen from the added columns 3, 4, 5, and 6. Column 3 gives output in horse-power per 1,000 revolutions. Column 4 contains the output steps, and column 5 the speed steps, in every case expressed in percentage of the lower figures. Column 6 gives the steps of the figures in column 3, hereafter called "frame step."

TABLE II.

1 B.H.P.	2 Revs. per Minute.	3 $\frac{\text{B.H.P.} \times 1{,}000}{\text{Revs. per Minute.}}$	4 Output Step.	5 Speed Step.	6 Frame Step.
			Per Cent.	Per Cent.	Per Cent.
¼	1,600	0·156			
½	1,400	0·357	100	14	129
1	1,400	0·715	100	0	100
2	1,100	1·820	100	27	154
3	1,100	2·730	50	0	50
5	1,000	5·000	67	10	83
7½	1,000	7·500	50	0	50
10	900	11·100	33	11	48
15	850	17·700	50	6	60
20	800	25·000	33	6	41
30	750	40·000	50	7	60
40	700	57·200	33	7	43
50	650	77·000	25	8	35
75	600	125·000	50	8	62
100	550	182·000	33	9	46

The irregularity in the steps of output and speed, and consequently in the frame steps, will give an indication of the difficulties which would face a designer if he were to attempt laying out a systematic line of machines on the basis of the present recommendations. On the other hand, the prospective purchaser of a motor when referring to this list is likely to find the speed given so far different from the one most convenient under the circumstances that he proceeds to send out inquiries without any reference to standards, whereas a table of 4 or 5 speeds would most likely contain one quite near enough to his requirements.

The output steps will naturally be smaller, the larger the machines,

I therefore suggest that we decide on three classes of machines: namely, small machines, frame figure below 10; medium-size machines, frame figure between 10 and 750; and large machines, frame figure above 750; that we fix the output steps for each class as follows:—

Small motors, output steps 100 per cent. to 50 per cent.
Medium-size motors, output steps 25 per cent.
Large motors, standardisation of these may be left to manufacturers for the present, as they are not made in quantities.

The outputs suggested are as follows:—

Small motors, ½, 1, 2, 3, 5, 7½ H.P.
Medium-size motors, 10, 12½, 16, 20, 25, 32, 40, 50, 62, 80, 100, 125, 160, 200, 250, 320 H.P.

The standard outputs should be used in all cases both for direct-current and alternating-current machines, so that the figures impress themselves on the mind. The first line of standard speeds must also

TABLE III.

Small Motors.

B.H.P.	Revs. per Minute.	B.H.P. × 1000 / Revs. per Minute	Output Step.	Speed Step.	Frame Step.
			Per Cent.	Per Cent.	Per Cent.
½	1,650	0·303			
			100	10	120
1	1,500	0·666			
			100	11	122
2	1,350	1·480			
			50	10	65
3	1,225	2·450			
			66	11	85
5	1,100	4·550			
			50	10	65
7½	1,000	7·500			

be chosen with approximately constant steps so that equal frame steps are obtained, especially for the medium-size machines.

Except so far as this consideration necessitated alterations, the present standard speeds have generally been maintained in the following tables III. and IV., which give the suggested first line of standard speeds.

These tables might be objected to on the ground that the number of different sizes suggested is too great, and the output step really smaller than necessary. That such criticism is unjustified, however, will be more clearly seen if we proceed to develop from the above line the lists of standard speeds possible for each standard output. These are obtained by lowering the speed of the larger or

raising the speed of the next smaller motors to that at which they are just capable of giving the respective standard output. The speed steps thus obtained will then be approximately equal to the frame steps in the above tables, *i.e.*, 65 per cent. to 120 per cent. for the

TABLE IV.

Medium-size Motors.

B.H.P.	Revs. per Minute.	B.H.P × 1000 / Revs. per Minute	Output Step.	Speed Step.	Frame Step
			Per Cent.	Per Cent.	Per Cent.
10	900	11·1			
12½	875	14·3	25	3	29·0
16	850	18·8	28	3	31·5
20	800	25·0	25	6	33·0
25	770	32·5	25	4	30·0
32	740	43·2	28	4	33·0
40	700	57·2	25	6	32·0
50	675	74·0	25	4	29·5
62	650	96·5	25	4	30·0
80	625	128·0	28	4	33·0
100	600	167·0	25	4	30·0
125	570	219·0	25	5	32·0
160	550	291·0	28	4	32·5
200	525	381·0	25	5	31·0
250	500	500·0	25	5	31·0
320	480	666·0	28	4	33·0

small, 29 per cent. to 33 per cent. for the medium-sized machines, and these figures, in my view, are by no means smaller than practical requirements necessitate.

Tables V., VI., and VII. are derived in this manner :—

TABLE V.

Small Motors (220 Volts).

B.H.P.	Standard Speeds.		
½	—	1,650	750
1	3,300	1,500	675
2	3,000	1,350	815
3	2,000	1,225	660
5	2,000	1,100	665
7½	1,650	1,000	—
10	1,330	—	—

TABLE VI.

Medium-size Motors (440 *Volts*).

B.H.P	Standard Speeds.				
7½	—	—	675	525	400
10	—	900	700	530	400
12½	1,130	875	665	500	385
16	1,120	850	640	490	370
20	1,050	800	615	465	350
25	1,000	770	580	440	340
32	980	740	560	430	330
40	925	700	540	415	315
50	875	675	520	390	300
62	850	650	490	375	285
80	830	625	480	365	275
100	780	600	455	345	260
125	750	570	430	330	250
160	730	550	420	320	240
200	690	525	400	300	—
250	660	500	375	—	—
320	640	480	—	—	—

Motors for less than 10 H.P. should be made for 220 volts as far as possible. The medium-size motors will in the majority of cases be made for 440 volts. They may be used for 550 volts, however, with merely an alteration to the field coils. As the steps from 440 volts to

TABLE VII.

Medium-size Motors (550 *Volts*).

B.H.P.	Standard Speeds.				
12½	1,130	875	665	500	385
16	1,120	850	640	490	370
20	1,050	800	615	465	350
25	1,000	770	580	440	340
32	980	740	560	430	330
40	925	700	540	415	315
50	875	675	520	390	300
62	850	650	490	375	285
80	830	625	480	365	275
100	780	600	455	345	260
125	750	570	430	330	250
160	730	550	420	320	240
200	690	525	400	300	—
250	660	500	375	—	—
320	640	480	—	—	—

550 volts is equal to the output step—*i.e.*, 25 per cent.—the list of standard outputs will hold good for 550-volt machines. Any standard 440-volt motor, fitted with 550-volt field coils, will at 550 volts give the output of the next larger standard 440-volt machine at a speed about 25 per cent. above its standard speed for 440 volts. The use of commutating poles allows of this being done without fear of sparking.

It will be seen that not only the outputs but also the speed figures are identical with those of the 440-volt list.

2. *Direct-current Generators for* 460 *and* 580 *Volts.*—Complete lists of these are immediately obtained from Tables VI. and VII. by adopting the principle that the standard 440-volt motor armatures are again to be employed without alteration. To make this possible the motor speed will have to be raised, which affects the outputs proportionately. The tables for 460-volt and 580-volt machines will again be identical.

TABLE VIII.

Medium-size Generators (460 *Volts or* 580 *Volts*).

Kilowatts.	Standard Speeds.				
9	—	1,080	875	680	530
11	1,320	1,040	820	640	510
14	1,300	1,000	780	620	480
17½	1,220	950	750	590	460
22	1,150	900	700	550	440
27½	1,120	860	670	530	420
35	1,060	820	640	510	400
45	1,000	780	615	480	380
55	970	750	590	460	360
70	940	720	570	440	340
85	880	680	540	420	325
105	850	650	510	400	310
135	820	625	490	380	295
170	770	600	470	360	—
215	730	570	440	—	—
270	700	540	—	—	—

3. *Polyphase Motors for* 50 *Cycles.*—The list of standard outputs for direct-current motors may with advantage be adhered to. It should apply as far as practicable to the standard synchronous speeds of 1,500, 1,000, 750, 600, 500, 428, 375, etc. This leads to Tables IX. and X.

All these outputs are obtainable with a comparatively small number of standard patterns by suitably altering the internal design only.

Polyphase Motors for 40 *Cycles.*—Here again the list of standard outputs may be maintained, at least for all medium size machines. Seeing that the step from 40 cycles to 50 cycles is 25 per cent., and

this equals the output steps, we may use the whole list of standard 50-cycle machines and run them as 40-cycle motors with correspondingly slower speed and the next lower standard output, without any alteration except to the stator winding. The list of standard motor outputs might also be adhered to should it be found desirable, in course of time, to proceed to the standardisation of totally enclosed machines, traction and crane motors.

TABLE IX.

Small Motors (50 *Cycles*).

B.H.P.	Standard Synchronous Speeds.	
½	1,500	1,000
1	1,500	1,000
2	1,500	1,000
3	1,500	1,000
5	1,500	1,000
7½	1,500	1,000

TABLE X.

Medium-size Motors (50 *Cycles*).

B.H.P.	Standard Synchronous Speeds.						
10	1,500	1,000	750	—	—	—	—
12½	1,500	1,000	750	—	—	—	—
16	1,500	1,000	750	600	—	—	—
20	1,500	1,000	750	600	—	—	—
25	1,500	1,000	750	600	—	—	—
32	1,500	1,000	750	600	—	—	—
40	1,500	1,000	750	600	500	—	—
50	1,500	1,000	750	600	500	—	—
62½	1,500	1,000	750	600	500	428	—
80	1,500	1,000	750	600	500	428	—
100	—	1,000	750	600	500	428	375
125	—	1,000	750	600	500	428	375
160	—	1,000	750	600	500	428	375
200	—	—	750	600	500	428	375
250	—	—	750	600	500	428	375
320	—	—	750	600	500	428	375

4. *Alternators.*—For the standardisation of alternators, it will be desirable, instead of making new patterns throughout, to employ as far as possible the mechanical parts of the polyphase motors. For this and other reasons, I suggest that the principle of 25 per cent. output steps be adhered to, and that the standard outputs in kilovolt-amperes

be as follows: 10, 12½, 16, 20, 25, 32, 40, 50, 62, 80, 100, 125, 160, 200, 250, 320, 400, 500 k.v.a.

It will be seen that these figures are the same as the B.H.P. figures suggested for both direct-current and alternating-current motors. This list would hold good for 50- as well as for 40-cycle machines, the same frames being employed. The standard polyphase alternators could of course be wound for single-phase, and in this case the list of outputs might again be left unaltered.

By way of example, the 500-k.v.a. size, if wound for single-phase, would be designed to give 320 k.v.a.

5. *Transformers.*—The output list of 3-phase transformers should be identical with that of polyphase alternators, so that the above figures are again applicable. It may be noted, that if a line of single-phase transformers were developed by using in all cases two cores of the standard 3-phase transformers, the output list need not be altered, the 500-k.v.a. transformer for 3-phase corresponding with the 320-k.v.a. size for single-phase, etc.

CONCLUSION.

It is hoped that the foregoing suggestions will not be considered as merely an attempt to further the one-sided interests of manufacturers. It should be clearly recognised that the proposed thorough standardisation is likely to be a success only if and in so far as it is to the advantage of both producer and user. A successful attempt in the interest of cheapness to introduce clauses not thoroughly compatible with reliability, or else to reduce unduly the number of standard sizes, is bound to defeat its own object. Engineers cannot be expected to adopt the Standard Specification and, wherever practicable, to adjust proposed plants so as to employ standard machinery unless it is clearly to their, or their clients, benefit to do so.

DISCUSSION.

Mr. Churton.

Mr. T. HARDING CHURTON: Dr. Pohl has referred to my Inaugural Address to the Yorkshire Local Section last year as an expression of the need for revision and development of the British Standards, from which it might be inferred that I had urged the adoption of certain standard sizes of electrical machinery as recommended by Dr. Pohl. In my address, however, though I urged the desirability of establishing agreement as to the definitions of terms used and the adoption of certain standard specifications respecting the performance of electrical machinery, qualities of materials, and other such matters; I expressed the opinion that the system of individual standardisation that was in vogue had left manufacturers free to develop their designs in a way that would not have been possible under a system of uniform standards of output and speed. One difficulty in the way of the adoption of certain standards of output and speed is the fact that there is so great a diversity in electrical supply systems. A motor that is made for a certain output when operating on

Mr. Churton.

one kind of alternating-current supply, will have a number of different outputs when wound for other alternating-current supplies; and it cannot be expected that these would always fit the listed standards. So that until electric supply authorities can be persuaded to adopt one or two standard systems of electricity supply, I cannot see much prospect of the general adoption of Dr. Pohl's suggestion with regard to standards of output and speed. With regard to rules for the rating and testing of electrical machines, upon which there exists great diversity of opinion and practice—which is attended by much inconvenience—it is to be hoped that the Standards Committee will revise and amplify their work in that connection. The testing of motors for six hours—regardless of size—is, as Dr. Pohl has shown, unsatisfactory. As regards the testing of motors for intermittent use, some experiments made in order to determine the relation between running for a given time continuously and for an indefinite period intermittently, may be of interest. A ventilated motor that was run for one hour continuously acquired the same temperature rise as when run at the same load for an indefinite period with an intermittency factor of 3 in 4; that is to say, run for three minutes, stop for one; a rate of intermittency, which is, I should say, considerably in excess of most requirements. When totally enclosed and run for one hour continuously, the temperature rise of the motor was equivalent to running with the same load at an intermittency of 1 in 3, while under the same conditions a continuous run of half an hour was found to be equivalent to an intermittency factor of 1 in 6. I do not suggest that these figures apply exactly to all motors, but as there is nothing in the Standards Committee Report to indicate what a continuous run of one hour is equivalent to in intermittent work, they may serve as a guide.

Mr. Robson.

Mr. W. E. Robson: The subject of the standardisation of dynamo-electric machinery is, I think, a subject not for a single discussion, but one which would merit, at any rate, a discussion once a session until something is done. All those who are acquainted with the Engineering Standards Committee recommendations know very well they are a dead letter altogether. Before we get anything in the nature of standards adopted we shall find there are one or two great factors which have to be overcome. We first of all have to embark upon a very great educational campaign; we have to educate all the engineers of the country and all the people who are using electrical machinery—and a great number of electrical machines are ordered direct from manufacturers by people who are not engineers themselves and who do not employ consulting engineers. Before discussing the terms that the recommendations of new standards should have, it is necessary to consider the reasons for the failure of the old recommendations, the provisional ones of 1904 and the final ones of 1907. I think we might take it primarily that, so far as we are concerned at any rate, standardisation was intended to benefit the electrical industry. It was intended to do that in two ways: first of all by enforcing such a

Mr. Robson. standard of performance as to encourage the use of electrical machinery and prevent unfair competition in selling machines, and, secondly, to lower the cost of manufacture of the machines to enable the makers to make fair profits while allowing cheaper selling prices, and with these profits to further the improvement of electrical machines and of the industry generally. Now with regard to the first point, the standard of performance, if the manufacturers of electrical machinery would agree among themselves to faithfully observe the standards which are going to be recommended by the electrical engineers of the country as a whole, and if it be made an offence against the law for foreign manufacturers to sell machines here with outputs quoted on their plates which do not at all conform to our ideas of performance, then something might be done. I see no other way, at any rate in Great Britain, as long as we have an open market here, for as the buyer in an enormous number of cases goes nearly wholly by the selling price of the machine and disregards the capital value of efficiency (and of temperature ratings also in many cases), foreign manufacturers, not being included in any agreement which might be made by our people, would always be able to exploit these failings. We are not likely to have any standards that we devise insisted on by Government laws as to guarantees on output plates.

Considering the other advantages of standards, if a full code of standards of performance, output, and speeds were adopted at once, the advantage would be much less than is generally supposed. During the past two years orders have been plentiful, and yet there is hardly a firm making a fair profit after establishment, selling, and manufacture costs have been paid. Cheapening of the cost of manufacture with the present absence of working agreements as to prices would only lead to such a reduction of selling prices as to reduce profits to the old level. There is also always the possibility of foreign competition. Further, when we consider how savings are to be brought about by the standards, we should, I feel sure, find they can only be very small. To start with, there is not enough volume of work in this country to enable what I term real manufacturing to be carried out. When we talk about manufacturing in the electrical industry, we ought to go and compare the way work is done in a dynamo factory with the way in which it is done in a cycle factory. The present system in some ways is ridiculously uneconomical. There are a certain number of, say, 5-H.P. motors required per week by the whole country. The orders for these are spread over some two or three dozen firms, and the result is that at the present time not one single firm in the country is manufacturing. It is not really manufacture. The result is that the savings are quite small.

If we take Dr. Pohl's Tables III. and IV. for machines with specific outputs 0·3 to 43·2, there are twelve sizes of machine. This is more than the average firm lists to-day, so that, as far as the number of frame sizes are concerned, there is no great advantage to be derived there. Further, these are the machines which are ordered in the greatest

Mr. Robson.

number and which therefore present the greatest facilities for manufacture as opposed to making. The parts of these machines which lend themselves best to manufacture are the purely mechanical parts, and with systematic design they are practically unaffected by the output and speed ratings. It is the specific output or torque rating which fixes their sizes. Armature hubs, winding drums, commutator hubs and clamp-rings, brushgear, shafts, bearings, magnets, end frames, covers, etc., are practically unaffected. The parts which are affected are the armature windings, and the labour cost on these is small. Complete armatures could be more safely stocked, but few firms would feel justified in carrying a much heavier maximum or minimum stock than they do at present. It can even now not be reckoned very safe to carry much in the way of stock armature windings because of their deterioration when exposed to air. We must not overlook a fundamental point in connection with electric motors. In very many cases—in fact, I should say the majority of cases—the motor is of very small cost in comparison with the machine or machines it drives, and one of our claims is that we can make it suitable for driving any machine. There is little hope of a man designing a machine costing £1,000 choosing his design to suit a particular recommended motor speed if the motor cost is, say, £50, unless he knows definitely that he can have no other speed given him. If it can be arranged definitely that there is only one set of speeds he can have, then of course he designs the machine to take those, but if he knows there is open competition among the manufacturers he will have the speed he thinks fit. When we know that makers of electrical machines cannot agree to limit cutting of prices, there is no hope that they will agree to what is to them a minor point, the limitation of speeds. There is also an element of time delivery in connection with motors. If the machine for which the motor is required is a very large one, there is ample time to build a complete new motor absolutely non-standard from beginning to end before the people are ready for it to be fitted to their machine. So there is not such a great advantage in manufacturing completely finished machines except on the quite small sizes. What is inherently at fault is that we have too many firms making one and the same size of machine. An agreement amongst them to pool the total orders, dividing them out in classes so as to give big enough orders for the size of machine parts to one firm to allow *manufacture*, would result in great savings in production cost and the limitation of establishment charges, advertising, and the like. The selling price could be lowered, designs improved, and at the same time fair profits realised. These profits would allow of development work and the employment of higher paid and better technical men. I believe that this unlimited competition amongst certain manufacturers so far from being good for the young electrical engineers is decidedly bad. Firms which are not making profits cannot be expected to spend money in development work—they cannot afford it. With the present bad paying condition of the electrical industry in this country, there is little hope or prospect of a big

Mr. Robson. English company finding money to buy up the existing firms. There is no prospect of such a company freezing out the smaller firms, as the latter's local and other friendly connections would keep them going, and it will be a very difficult matter to bring all the firms together to a working agreement among themselves, as there are so many. But I do not think it should be a hard matter for, say, a dozen firms to join themselves together and to come to an arrangement to pool their orders in a certain ratio dependent upon their capitals and so on, and to divide the work out in classes.

Considering certain details of the paper on the machines where manufacture and standardisation is most required, I do not think that the practice of specifying methods as well as the results to be secured obtains nearly so much now, and certainly the Government departments are the greatest offenders. With regard to ratings, I agree with Dr. Pohl that machines good for six hours on full load are practically always good for continuous operation. But I see from that no reason why the six hours should be left out of the standard specification. It might, however, be stated that the passing of this and the other prescribed tests shows the capability of the machine to work from week-end to week-end. With regard to intermittent ratings, we shall always have trouble. Here we are faced with the desirability of the buyer or his engineer knowing the load factor on which his machine operates. If he knows this, he could also draw up a load curve, and then it is easily possible to test the machine to the load curve for a length of time depending on the size of the machine, so that it can work continuously on that rating. The present time ratings have been evolved from guesses as to the load curve. It is hardly possible for us to prepare standard load factors except for such drives as ordinary cranes and ordinary machine tools and the like. As regards classification, I feel that electric motors will eventually be prohibited in such places in mines where there is the slightest danger of explosion or the like being caused by any failure in the electrical supply, and I think we should face the tendency of legislation to eliminate chances of loss of life through this apparatus. Flame-proof motors would be better left out of a standard specification. With regard to the wearing depth of commutators, the present standard recommendations are simply unnecessarily generous. It would be better to have a standard for minimum safe-wearing depths as averaged from present-day practice, as then manufacturers could make talking points about extra depths on their machines if they liked to provide such. Dr. Pohl has given figures for wearing depths in a commutator which are quite on the generous side. My own practice was, on commutators up to 6 in. diameter, to allow $\frac{3}{8}$ in. wearing depth; from 6 in. to 10 in. I only allowed $\frac{1}{2}$ in.; from 10 in. to 18 in. $\frac{5}{8}$ in.; from 18 in. to 24 in. $\frac{3}{4}$ in.; and above 24 in., 1 in. Some of these commutators I have been referring to have been in use for twelve years and have not been replaced by new ones. As the rate of depreciation which would have to be allowed on electrical machinery is 10 per cent., I think those depths are quite sufficient.

Communicated: While agreeing with the proposal to have the standard overload capacity for open-type machines fixed at 25 per cent. for 1 hour, without sparking, and 100 per cent. without injurious sparking, I think that 100 per cent. momentary overload is advisable for motors for intermittent working, owing to the load-time curve that they have to work on seldom being accurately known, and to save reproach from breakdowns. A list of minimum efficiencies and power factors is highly desirable, especially seeing the natural tendency to increase outputs by forced ventilation and interpoles, etc., at the expense of efficiency. It should be compulsory to state, at any rate, full-load efficiency on output plates and in tenders. With regard to the determination of efficiency by the "loss" method, it would introduce too great complications to have to make allowances for the different contact losses of various types of brushes. It would be better to insist that the armature resistance measurements are to be taken for different currents up to full-load value, and to include the brushes in the circuit. Armature plus brush resistance can then be shown in a curve against varying armature currents. There will be some difficulty in fixing the allowances to be made to cover variations with load of the iron loss as the allowances should be different for weak and strong field machines and for machines with small or large armature reaction. With respect to proposed standards for insulation, troubles would certainly arise in attempting to enforce impregnation of all materials, such as cotton and paper, before winding, and to standardise impregnation after winding will be useless without strict definition of "impregnation." Even with vacuum ovens and pressure impregnation, and with untaped field coils, it is very doubtful if the varnish reaches the innermost layers of the winding, whilst with the quite usual practice of impregnating after fully taping the coil the varnish generally enters only a short way. The deeper the coil then, the less effective is the impregnation. Mr. Robson.

Considering proposals for specifying higher air temperature, it would be advisable to insert requirements as to the minimum softening temperature for the materials used for insulating bushes and the like for terminals, brush spindles, etc., as troubles have arisen with these parts in hot and moist situations. For determining the temperature rise of field coils there is, of course, no doubt that the present nearly universal system of measuring the rise by a thermometer on the surface of the coil is no real safeguard, and no valid reasons have been adduced why the Standards Committee recommendations should not be upheld. The resistance method is really much simpler than the thermometer method; it is certain in giving the mean temperature, and allowances as to permissible mean temperature could easily be formulated to take account of the different ratios of maximum to mean temperatures in different thicknesses of coil. There must always be grave doubts with ordinary thermometer tests as to whether the thermometer was actually on the hottest part of the coil surface. Further, the common practice of taping the coils all over, while quite unnecessary as a protection, except perhaps in the case of,

Mr. Robson. say, traction motors, is quite unfair to the buyer, for it masks the real surface temperature of the coil and minimises the advantages of impregnation. Dr. Pohl's suggested thermometer method is certainly much better than the ordinary method, and a similar device has been used for some time on experimental coils at the City and Guilds (Engineering) College. It has, however, two disadvantages: on actual machines specially shaped thermometers are required, and there is still the doubt as to whether the bulb is at the correct depth to show the maximum temperature.

The objection raised by the author as to resistance measurements necessitating the presence of the buyer's engineer both at beginning and end of test, obviously applies to any method whatever, for otherwise he has no certainty, except the maker's word, that the load or field current has been on the machine from the beginning. As regards temperature rise in distributed windings generally, there is, as a rule, no difficulty in applying a resistance method, and a testing set can easily be devised which would show either the resistance or the average temperature rise of the windings more quickly and with much greater accuracy and safety than any thermometer method. Considering the proposals as regards duration of tests, it is surely wrong to determine these solely from temperature rise considerations, for a 1-hour or even a 2-hour run is not sufficient to show the mechanical soundness and the electrical goodness of all the machine parts. Notably is this the case with brushgear and insulation. Whatever times are finally decided on, the machine output plates should give the output guarantee and the test time. I agree that there is no real need now for fixing 115 volts and 110 volts as standards for machines. The demand for machines for these voltages is very small, and the engineers for a 3-wire system with 200 volts across outers would certainly object to motors of appreciable size being connected across the inner wires. Probably 500 volts is a better standard for motor voltage than 550, as corresponding more to the usual cases of supply voltage. We must consider ourselves as being far from standardisation of frequency for some time yet, for if railway main-line electrification were brought about on an alternating-current system, and advantage taken of their long mains to develop power schemes, we might find need for frequencies even lower than 25.

The present standards recommendations as regards outputs and speeds are quite useless, and they bear no relation whatever to the real demands for machines made on the makers. The frame sizes should be based on suitable torque or specific output steps and not on horsepower steps. A fair idea of what has proved necessary in the past may be obtained from a study of the frame sizes and outputs as found in the lists of the leading makers of electrical machines. Having analysed a great number of these lists, I find that considerable differences occur in makers' ideas as to the number of frame sizes necessary between any limits of torque rating, but by plotting torque against successive frame sizes and starting at about 3 H.P. a mean curve is easily found. It appears

that from (H.P. × 1,000)/R.P.M. = 2·5 to (H.P. × 1,000)/R.P.M. = 50, steps of 50 per cent. in torque rating would meet requirements, while for the quite small motors steps of 100 per cent. would be sufficient. This method gives a less number of frame sizes than the author recommends, and is therefore more acceptable from a manufacturing standpoint. If tables of what are to be considered small, medium, and large motors are to be drawn up, I consider that the basis of the tables should depend upon the nature of the mechanical design and machine operations necessary. It would be better to have motors up to 2·5 specific output in one class, those from 4 to 50 in another class, whilst motors above that size might be in a third class. The manufacturing methods for a 5-H.P. motor are more akin to those on a 20-H.P. motor than they are to those for a ¼-H.P. motor. The question of dynamo ratings may be decided by consideration of the outputs of the same frame sizes and windings used on motors, but the number of dynamos being so small in comparison with the motors makes careful consideration not so important. As regards specifications for standard speeds, these must be obtained by considering how few armature windings are advisable for each frame size, and the speed for these at the standard voltages, always bearing in mind the possibilities of altered horsepower and speed by change of the coil connections to the commutator. It would appear advisable to have a range of higher standard speeds, for machines up to 50 specific output, than those given in the paper. There are a fair number of these machines required, and if the standard machines are safe for these higher speeds, additional safeguards as to reliability are furnished at the lower speeds. **Mr Robson.**

Mr. Hammond. Mr. Robert Hammond: I feel it is due to the Committee which settled the standards to say a few words in defence of what they did. In the first place, they had before them two objects. One was, while bearing efficiency thoroughly in view, to cheapen the cost to the buyer. Their first step was carefully to consider what were the various sizes of generators and transformers in more general demand, and at the same time what were the sizes which the bulk of the manufacturers were prepared to make. From those sizes they selected their list. I desire to say how heartily I appreciate this paper. It is by criticism such as this that the Standards Committee come into touch with those who have studied the subject for themselves, and I am sure that had the author been able to help us in the prehistoric days of 1902–3–4, we should have been very delighted to have had his help. The Committee, which will shortly make a fresh start, fully agree with the author that it must from time to time revise its work, and will, I am sure, at its first meeting very thoroughly go through this paper and talk it over with high appreciation. But I would be very sorry indeed if any one left this meeting thinking that the work of the Committee was arrived at in a haphazard manner. I draw your attention to the constitution of the Committee. There were representatives of those who had the testing of machines for the Admiralty; there were those who repre-

Mr. Hammond. sented the purchase and testing of machines for the War Office; there were those who represented the Crown Agents for the colonies. Then there was Dr. Glazebrook, who represented the National Physical Laboratory. And in that connection I would point out that those important tests which the author has described to us were all done, I will not say at the direction, but at the instigation of, this very Committee. This Committee felt that the haphazard method of dealing with temperature rises, which had been in practice for so many years, was unsound, and they invited the National Physical Laboratory kindly to assist them in considering what were the temperatures that dielectrics generally would stand. Therefore all this good stuff set out in the author's paper belongs to us. Then there was also on the Committee Mr. Antill, of Siemens Bros.; there was Mr. Essen, with a manufacturing experience of over twenty years; also Mr. Philip Dawson, Captain Sankey, Mr. Eborall, Mr. Robert Hammond, Mr. Highfield, Mr. Patchell, and Mr. Sparks. Now all these gentlemen who had been for years purchasing and testing machines, and others who were manufacturing machines, hoped by round table conferences with leading manufacturers, which lasted for some years, to evolve a set of rules which would be acceptable to the industry. They had in mind two objects—one, as I say, to choose those sizes, which might not have been the most scientific—the author has got out a list of his own in which in the most wonderful manner the ratios are identically the same all through the uprising scale—but those sizes of which the manufacturers had the patterns in their shops, the making of machines from which would not involve any extra capital expenditure. They also had in view that it was not sufficient only to choose sizes that were suitable, but such conditions of test had to be laid down that the consulting engineer—always ready to do his best for his clients and always ready to show that thorough tests had to be made—should be somewhat held in check. They therefore said, "Let us lay down such simple tests that even the most covetous of consulting engineers cannot make such an undertaking about the testing as will take an undue sum of money out of the purchaser's pocket." They thereupon decided, "If this machine will stand this test for six hours within this temperature rise, and at this rated load we consider the buyer should be satisfied." But what the author recommends in this paper—I welcome him as a friend to the consulting engineer for it—is that when I go down to test one of these machines bought under his proposed specification I shall have to take three weeks luggage, all my staff, and perhaps my wife and family, because I have to challenge the manufacturer to prove to me, the consulting engineer, that with suitable attention—and I am quarrelling all the time as to what is "suitable attention"—the machine will work continuously, not for six hours, which would send me back by the next train with a few paltry guineas in my pocket, but from week-end to week-end! Now the specification adopted by the Engineering Standards Committee provides a test which we all know in our hearts is a test which when

once supplied will secure us a good machine. If a machine will run for six hours within these temperature rises, then we know we can give a certificate that it is a well-built machine. I am certain that if the author had been on the Committee which arrived at that conclusion he would have felt with us that talking of this week-end to week-end business was giving a chance to some one to pile up big expenses before the machine was taken over. Mr. Hammond.

Before I sit down I wish to point out to the author a little slip he has made. He said that he gathered that under the Standard Specification a generator had to be built in order to work in an atmosphere of 25° C., and he implied that if such a machine was ordered for the King's Durbar it could not work because it would probably be run in an atmosphere of 35° C. I would point out that there is nothing whatever in those prescribed tests which justifies him in saying that the Committee specified the machine should be such as to work in an atmosphere of 25° C. [Dr. POHL: I have not said so.] Mr. HAMMOND: Dr. Pohl says he has not said so. He quarrels with 25° C. and says he thinks it ought to be 35°. We prescribe in this specification a certain rise of temperature; we prescribe 60° C., but we say that 60° C. rise in temperature is a rise upon the surrounding atmosphere of 25° C.—total 85° C. If I have occasion in the author's own native city of Leeds to test machines with an atmosphere of 37½° C., then instead of permitting a rise of 60° C. I must take off the 12½, and still get a final temperature of 85° C. as on the basis of an initial temperature of 25° C. That is all we say. We say that these rises of temperature are based upon the supposition that 25° C. is the atmosphere of the room, but if the air temperature of the room in which the machine is to be used in actual service exceeds 25° C., then each of the temperature rises specified in Clause 12 is to be decreased by 1° C. for each degree of increase between the room-temperature and the 25° C.

I would have liked to have had from the author one acknowledgment of the bright thing in that specification. For the first time the Committee swept away the absurd idea of specifying overload. It has always appeared to be an absurdity first to specify a machine of, say, 1,000-k.w. capacity which can work at a certain temperature rise, and then in the last clause of the specification to stipulate that it can occasionally do 25 per cent. more. When we were face to face with that proposition on the Committee we said, "No, let us say to the profession that this is an absurdity and let us use the expression "rated load"—that is, the actual load at which it will bear this temperature rise, but as for your 20 per cent. for half an hour or three hours, or ten hours, it is too foolish. Therefore one of the things we tried very hard to do, and which we have succeeded in doing, was to abolish all reference to overload, but the author comes here to-night and blames us for omitting to specify it.

Dr. SILVANUS P. THOMPSON: Allow me first of all to express my entire disagreement from one recommendation of the author's. He advocates the elimination of machines working at 100 or 115 volts as Dr. Silvanus Thompson.

Dr. Silvanus Thompson.

standard machines. Now I have been a persistent advocate for the utility and advantage—at any rate, from the point of view of the consumer—of having that low voltage of 100 or 110 volts in one's house. Surely the present experience with metallic filament lamps at their present cost warrants me in saying that it has been a misfortune from the point of view of the consumer that every electrical engineer has taken to the fashion of distribution at 250, 440, and 550 volts. We ought to keep 100 or 110 volts as a standard voltage. A fortnight ago I had something to say about the use of the word "regulation." It turns up again on page 182: "The present rules provide that the regulation of alternators shall not exceed 6 per cent." What the author means is that the departure from perfect regulation shall not be more than 6 per cent.; that is to say, the irregulation will not be more than 6 per cent. There is one matter which I wish to put before the Institution. There is some danger—it occurs again and again in this subject of temperature rise—of confounding temperature rise with the actual temperature reading because of the way it is printed. You speak, for instance, of a temperature rise of 40° C., and of a room-temperature of 35° C., using the same degree symbol—the little circle—whether degrees as read on the thermometer are meant or the additional degrees of rise. For many years I have adopted a practice with which I am not satisfied, and I want somebody to suggest a better one. Always when I write 40° C., that means the temperature of 40 as read on the thermometer, and not the rise, or the difference, or anything else. If I want to speak of a 40° rise of temperature I write it "40 Centig. deg.," and do not use the little round symbol. It may come to very much the same thing, but that little difference in the way of writing is sufficient to make it clear to me. But it is not a difference that is at once clear to everybody else. Perhaps some other person has overcome the difficulty in a better way, and if so I shall be glad to hear if that is so. Lastly, I want to point out that it is not at all necessary to have a six-hour run, or any other long run, in order to find out what will be the top temperature attained by a machine under conditions of regular operation. Here is a very simple process. In observing a heat-run we know that the temperature at first rises steeply, perfectly regularly, minute after minute, the plotted curve going up a sloping line. Then after some time it turns over, and the rise per minute becomes less and less until, when the temperature has got up to near the top value, it practically rises very little more. Now from these facts we can, in a run that lasts less than an hour, get at what the top value will be. Make a few observations very carefully at the beginning; find the temperature rise per minute; then go on for some time, and take some more readings, and observe when the temperature rise has got to such a point that it is going up half as fast as it was at first, that is, the point when the amount of rise per minute is exactly reduced to half what it was at first. Then we have got half-way up to the top. We can see how much it has risen—suppose it has risen 14°. We double that, making 28, and that will be the top value of the rise. It is quite a simple thing and quite accurate.

Mr. HERBERT A. JONES: As his friend, the author will possibly allow me to differ with him on one or two points. When we were before the Standards Committee in 1903 we had full opportunity, as the manufacturers of electrical machines in this country, of having the question fully put before us; and when the author just referred in such scathing terms to the Committee, I do not think he was aware that most of the supporters of that Committee were to the right and left of him. The standard list was arrived at in this way. We were called to two meetings, and we were asked to suggest speeds; and, with that beautiful selfishness which characterises the British manufacturer, we all suggested our own particular speed. I believe the Committee went into the next room, tumbled all the suggestions in a hat, got out the average, and gave us that as the standard! But that was a start at standardisation, from which, I maintain, most manufacturers have benefited. The author raises the question of Continental competition. To my mind, if there is anything in Continental competition, and if the benefits of standardisation are what Dr. Pohl contends they are going to be to us, we should feel the effects of that competition in standard small machines. But we do not; where we do feel it is in big and specialised schemes involving larger machines. I maintain that with regard to motors from 5 H.P. to 100 H.P. the Germans have not the slightest chance against the present English prices. While I do not believe in being too conservative, I think we must not go too far in the matter of standardisation of design. If standardisation is carried out to the extreme to which it has been in America, it will affect all initiative and consequently stultify design. Take, for instance, the American standard for engine generators. They even specify shaft bearings, armature hubs, and commutator bushes. It is quite a different thing for a Committee to arrive at a certain limit of standardisation and not to go beyond that limit. If it does, then British manufacturers of electrical machinery will never keep the pre-eminent position they at present occupy. Incidentally, the author said that to go in for excessive commutator depths was a useless investment of capital. I think the contrary is the case. Any depth of commutator is a useful investment of capital for the British public at present prices! With regard to sparklessness, I think it is dangerous to have a machine defined as having "practically no sparking." We thought we had done away with sparking years ago, but "practically no sparking" depends entirely on the gullibility of the buyer and the plausibility of the seller, and it has involved many firms in more serious losses than they care to admit. I think also the term "momentarily" should be defined. It seems a very long time if one happens to be standing alongside a machine which has to go through that momentary overload. It certainly should be defined in seconds or decimals. Although I do not wish to intrude on the ground of the designer, I believe if we go to the high temperature rises of 120° C. or 125° C. we may meet with a difficulty which has occurred in machines in the past. Until a machine gets to its final temperature it has to rise in speed owing to the coefficient Mr. Jones.

Mr. Jones. of the increase of resistance of copper. If we go to a higher internal degree of temperature in that machine, we are going to have a steeper curve of speed variation from the cold till the machine is hot. If there is one advantage which we have successfully claimed for electrical driving it is that the variation of speed over a day's run is so small, and this in direct-current motors is due to the small temperature-rise in the field coils.

I agree with the author in his attempt to revive the temperature test of field coils by a resistance method. If it was possible to carry out the armature measurement in the same manner I should advise that being done, because there is no more uncertain and variable quantity than the thermometer in the hands of some testers. I agree with a previous speaker that standardisation is proving more valuable now. We do not have the absurd enquiries we used to have, which specified that "the armature should be made of so-and-so, and insulated with paper between the discs, and so on." If we only bring ourselves into line on some general heads of standards the electrical industry of this country would never look back. There are one or two points arising out of that with regard to the value of a guarantee. I want to point out that if you are selling ten machines you will sell one to a consulting engineer who is particular and wants a "week-end party," such as Mr. Hammond has mentioned, but you will sell the other nine to men who want a good and robust machine which will stand by them and not let them down, consistent with price. It all comes down to price at the finish, but there are exceptions. I know a case where a certain contract was lost simply because the firm quoting for it could not guarantee an efficiency of a certain figure. Another firm guaranteed that efficiency, which was an impossible one. I said to the gentleman who had the matter in hand, "We can guarantee you so-and-so under a penalty of so much and a bonus of so much." I did not see anything of him again until a week afterwards, when he told me our offer was refused. He told me who had obtained the contract, and I enquired if he had obtained the required efficiency. He replied in the affirmative, adding that not only had they obtained it, but that it was 1½ per cent. more than I had guaranteed. I then asked what guarantee he had that the required efficiency would be obtained. He replied he had arranged that he need not take the machines if they did not come up to the guarantee. Gentlemen, there are men buying electrical machinery who know little of specifications, but they know even less of the provisions of the Sale of Goods Act. That shows that in the majority of orders which electrical manufacturers get the goods are not sold on strict conditions of a guarantee, but that many people buy machines simply on the reputation of a firm.

Mr. Burnand. Mr. W. E. BURNAND: I think it will be generally agreed that there is room for improvement in the present standards, but we shall have to go slow, and standardise tests rather than machines. I should like to take up the line of Dr. Pohl and make a few suggestions on some of the tests he specifies. The term "week-end to week-end" applied

to the requirements for continuous working is largely superfluous, and is not a very good way of putting it. A better way would be, "The machine shall be able to work continuously with ordinary cleaning or attention not oftener than once a week, and to comply with the specified tests." With regard to "no sparking," a suggestion I would like to make is that the sparking should not be specified, but its results. It might be put, "The ratio between the roughened and polished portions of the copper commutator surface passing under the brushes must not exceed a certain limit after six hours' full load." It might be put at 5 per cent., or 0·5 per cent., or whatever value may be decided as a reasonable maximum limit. These two suggestions imply no lengthening of the test, unless the performance in the other specified tests is not decisive on these points. The temperature rises stated in the paper look high, but taken broadly I am in agreement with them. With regard to the standardisation of speeds something might be done, but I am afraid not much. I would prefer to see the last 5 revolutions omitted from some of the speeds in the tables. Table X., relating to alternating-current machines, does nothing more, of course, than specify the number of poles, but what the user actually works on is the actual speed, and I think that these speeds might be of more service than speeds which are merely another way of specifying the number of poles for which the machines are wound. The comparison between 40- and 50-cycle alternating motors is not quite fair to the 40-period machine. On 40 periods the hysteresis losses are somewhat less, and also the magnetising current is less, for a given flux, so this may be somewhat higher for a given loss or temperature rise; the reduction in output is hence rather more like 15 per cent. than 25. Mr. Burnand.

Mr. F. T. CHAPMAN (*communicated*): With regard to the author's suggestion for the testing of machines under Rating (A), although I agree with his arguments under "Duration of Temperature Tests," I consider the case of rotating machinery to be essentially different from that of static machinery like transformers. The object of the official test is not solely to determine the rise in temperature, but also to prove the mechanical qualities of the machine. If the test is stopped short before the maximum temperature is reached, the most trying part of the test is eliminated. This applies particularly to commutator, brush-gear, and other parts in which built-up insulation may be employed, as well as to bearings, etc. For this reason I think the six-hour test should be retained as hitherto. I agree with Mr. Jones that the phrase "practically no sparking" is unsatisfactory. The framing of this clause is likely to be a difficult matter. It might be possible to specify that the voltage drop across any brush contact should be of uniform sign over the whole contact area, and should not exceed a certain figure at any point. Some prohibition of "blackening" should also be included. The internal thermometer device proposed for field coils is ingenious, but few modern designs of field frame admit its application, except in large sizes. As Mr. Jones pointed out, the increase in speed with rise in temperature is a very important matter in shunt motors, and Mr. Chapman

Mr. Chapman.

this fact is likely to set the limit to the temperature rise, rather than the effects on the insulation. For instance, the 60° C. rise suggested by the author means approximately 24 per cent. increase in resistance and 6 to 10 per cent. or more increase in speed. In a standard specification a clause limiting this variation is desirable. Although the temperature rise of commutators is not touched on in the paper, I think an extension of the present limit to 60° C. would be permissible.

Mr. Cooper.

Mr. W. R. COOPER (*communicated*): As the author deals with the question of temperature tests, and Dr. S. P. Thompson has pointed out that such tests may be considerably curtailed, it may be well to look into the question more closely, particularly as there seems to be a general want of clearness on the subject of heating curves. So far as I am aware, the results here given have not been pointed out previously. If the curve of heating is plotted, as in Fig. A, a logarithmic curve

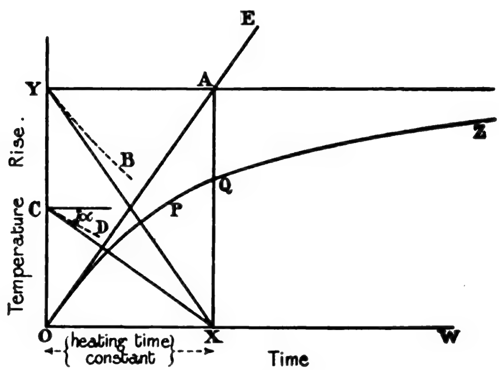


FIG. A.

should theoretically be obtained. The curve is such that if Y is the steady temperature attained, O being atmospheric temperature, and O A is the initial rate at which the temperature of the machine rises, then Y A or O X is a time which, from analogy with the rise of current in an inductive circuit, may be called the "heating time constant" of the machine, and this time is such that at its expiration the temperature reached is 0·63 of the maximum—that is, Q X = 0·63 A X. I think it is rather unfortunate that the author has christened another quantity a time constant, whereas the time O X, by analogy and previous usage, merits this class of title. The line O A is the tangent to the heating curve O Q Z at the origin, and therefore the angle X O A is found readily by observing the rate at which the body rises in temperature initially.

It would be an advantage if the ultimate rise of a machine could be predicted without the necessity of running a prolonged test. There does not seem to be any easy method of doing so for rotating bodies, such as armatures and commutators, as continuous records of temperature cannot easily be obtained in such cases, and therefore the angle

AOX is not available. Fortunately, however, the temperature of the field magnets, or stationary part of the machine, is generally that which limits the output, and therefore a short temperature test may be useful even if restricted in this way. It is obvious that if the heating time constant, which depends only on the volume and materials of the machine, could be found easily, the maximum temperature rise would follow. Unfortunately this quantity is not easily found directly. But the desired result can be obtained in another way. The heating curve is found mathematically by assuming that the machine radiates at a rate proportional to the temperature rise. Also, when the maximum temperature rise is reached the machine is of necessity radiating (using this term in a broad sense) at the same rate as it is tending to heat up due to the energy being supplied; that is, at the rate given by tangent of the angle AOX. In other words, if the machine is raised to the temperature Y, and then allowed to cool, a curve such as YB will be obtained, and the angle which the tangent to this curve at Y makes with YA must be equal to the angle AOX; whence it follows that the rate of cooling is found by joining X, Y, if these are known. It is not necessary, however, to take the machine up to the maximum temperature Y. Suppose it is taken up to the temperature C. Then since the rate of cooling is proportional to the rise of temperature it follows that the rate of cooling for this temperature is found by joining C to X. A possible method, therefore, at least theoretically, is to run the machine for a short time, say half an hour, so as to get the initial rate of rise of temperature, that is, tan AOX, and therefore the angle AOX. Then load up the machine as far as possible, if time is a consideration, until any convenient temperature rise C, say 30° C., is reached, remove the load and excitation but keep the machine running, and observe the cooling curve CD. This is plotted, the tangent at C is drawn, and the point X where this intersects the axis OW gives the heating time constant. Erecting the ordinate through X gives the maximum temperature rise by the point of intersection A with OE. As to whether this process would give a correct result is, perhaps, doubtful on account of the distribution of heat. The same information, however, can be obtained from the heating curve itself without having recourse to a cooling curve. It is only necessary to remember that the rate of heating at any temperature given by any point P on the curve is equal to the initial rate of heating less the rate of cooling. Thus the rate of cooling at any temperature P is found by subtracting the rate of cooling at this point of the curve from the initial rate of heating. The rate of heating at any point of the curve is, of course, easily found graphically. Since the rate of cooling is proportional to the temperature rise, the temperature at which the rate of cooling will be equal to the initial rate of temperature rise (*i.e.*, the maximum temperature rise) is found at once arithmetically. This process sounds a little complicated but is quite simple, as an example will show. Suppose the initial rise is at the rate of 40° per hour, and that at 30° rise the rate has fallen to 25° per hour. Then the rate of cooling at the temperature of 30° is

Mr. Cooper.

Mr. Cooper. $40 - 25 = 15°$ per hour; and this rate of cooling will rise to 40° per hour if the temperature is raised to $(40/15) \times 30 = 80°$, which, therefore, is the maximum temperature-rise. The method mentioned by Dr. Thompson of running a machine until the rate of temperature rise falls to one-half the initial rate, the maximum rise being then double the rise at which this occurs, is a particular case of the above. Any temperature can be taken, but in order to have the least error it will probably be best to select temperatures somewhat above that corresponding to half the maximum rise—in fact, at a time equal to about three-quarters of the heating time constant from the start. In any case two or three temperatures should be taken to see that the results are consistent. It may be that the maximum rise is all that is desired, but the heating time constant is a useful quantity, and is found at once by drawing the line C X from the point C (the temperature taken) at an angle α such that the rate of temperature fall is that found at P. The intersection of C X with O W gives the desired quantity, and this is useful because the temperature rises to 98 per cent. of the maximum in a time equal to four times the heating time constant. In practice, heating curves are not quite logarithmic, but they are nearly so, and I think this method can be used with a fair degree of accuracy. As an example of the sort of results obtained the following values are calculated from Fig. 10 of Dr. R. Goldschmidt's paper on "Temperature Curves and the Rating of Electrical Machinery," * the corrected curve marked B in that paper being taken.

RESULTS FOR 75-K.W. GENERATOR.

Approximate Time from Start.	Temperature Rise Selected.	Rate of Heating per Hour.	Deduced Rate of Cooling.	Calculated Maximum Rise.
0	0	$42\frac{1}{2}$° C.	0	—
55 minutes	30° C.	18° C.	$24\frac{1}{2}$° C.	52°
$1\frac{1}{4}$ hour	35° C.	$12\frac{1}{2}$° C.	30° C.	$49\frac{1}{2}$°
$1\frac{3}{4}$ "	40° C.	9° C.	$33\frac{1}{2}$° C.	51°
$2\frac{1}{2}$ "	45° C.	$4\frac{1}{2}$° C.	38° C.	$50\frac{1}{2}$°
			Mean ...	51°

The mean result of taking four points on the curve is 51°, and the actual maximum given by Goldschmidt is 52°, which is in fair agreement considering that the figures are merely taken off the printed

* *Journal of the Institution of Electrical Engineers*, vol. 34, p. 676, 1905.

diagram. Points at lower temperatures did not give such good results. Mr. Cooper.
The heating time constant of this machine is given as 75 minutes. From such curves as those in Fig. 2 of Dr. Pohl's paper the maximum rise and the heating time constant can be deduced quite quickly.

Having gained this information, it is a simple matter to construct an approximate diagram for intermittent working. Suppose we have the heating curve shown in Fig. B for a machine with a heating time-constant of 75 minutes, and a diagram is desired for the machine used intermittently, loaded for 5 minutes and unloaded for 5 minutes alternately. At the end of the first 5 minutes the temperature will rise to A. The machine will then cool at the rate given by joining

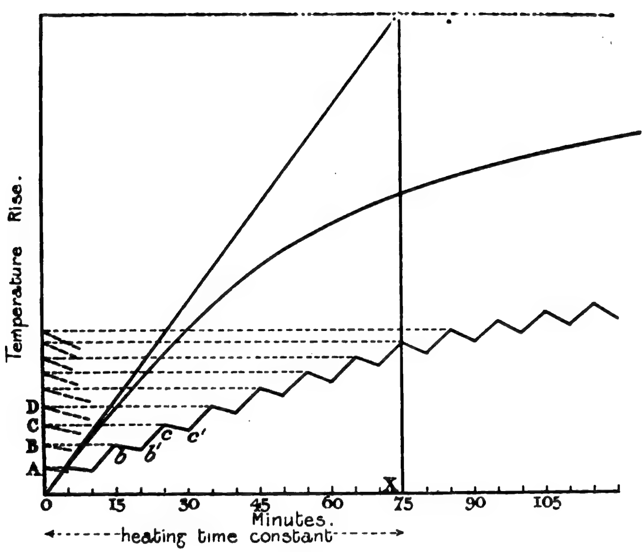


Fig. B.

A to X, and thus the diagram during the second 5 minutes is parallel to AX. During the third 5 minutes it is parallel to the heating curve at the corresponding temperature. At the end of 15 minutes the temperature has risen to B, and then falls at the rate given by joining B to X, so that the part *b b'* is parallel to B X. Similarly, *c c'* is parallel to CX, and so on. The various parts are here roughly drawn straight, but for longer intervals it might be necessary to make them curved, it being borne in mind that every part of a cooling curve is parallel to the line drawn to X from the corresponding temperature on the axis. If only the maximum temperature rise is required it would not be necessary to go through all the graphical construction if it is borne in mind that for equilibrium the total heating must be equal to the total cooling over the respective intervals of load and no load.

Mr. James. Mr. W. H. N. JAMES (*communicated*): I should like to support the suggestion made in connection with the issue of copies of "Standards" to members of the Institution, which, if it can be carried out, might well be extended to other standards affecting electrical engineers. As regards the measurement of temperature rise, the suggestions made are of quite a revolutionary nature, and I can hardly realise that the resistance method is too difficult for the average engineer to carry out; if this is the case, it is an argument in favour of the better education of engineers rather than against the use of the method in question. Further, the method suggested by the author would be difficult to carry out in many cases, particularly when dealing with enclosed or protected machines, though it might be facilitated by arranging the distance-piece at right angles to the position shown in the diagram (*i.e.*, pointing towards the centre of the core). I should also like to ask if any results have been obtained bearing on the relative temperature rises in the interior of coils in the upper and lower halves of field magnet systems. In connection with the number of suggested sizes of motors, I think these are too few as regards the smaller sizes of 3-phase induction motors, such as would be used for the individual driving of looms. A point not dealt with in the paper, and one which would well bear discussion, is the standardisation of pressures, and more particularly frequencies, for motors used for single-phase traction. Judging from information contained in a recent paper by Mr. J. B. Sparks,* considerable diversity of practice exists on these points, particularly abroad, and it would probably be preferable to go into the matter thoroughly at once rather than wait until several pressures and frequencies have been largely installed.

Mr. Scott. Mr. E. KILBURN SCOTT (*communicated*): In order to sell machines we must be able to compete in price as well as in quality, and in case of overseas business it also means that the orders must be systematically sought after. For many years our electrical manufacturers were so busy competing for municipal plants that the overseas business was somewhat overlooked. Later on, when manufacturers directed their attention overseas, they found that foreign firms had already secured a strong foothold. The amount of electrical apparatus supplied to Australia, New Zealand, and South Africa, etc., by foreign firms has been very large indeed, and they have secured it for two reasons: first, greater energy displayed in seeking the business; and secondly, low prices for standard machines kept ready for delivery. The author has clearly shown that owing to lack of standardisation, and to having to make machinery to freak specifications, our manufacturers are severely handicapped.

Regarding rating, I would like to see the actual figures stamped on the metal of the machine itself, because the usual small brass name-plate lends itself so easily to abuse, especially for motors for abroad. For example, there is the practice of stamping the correct rating of the machine on the name-plate affixed to it, and then sending out a

* *Journal of the Institution of Electrical Engineers*, vol. 47, p. 816, 1911.

Mr. Scott.

blank name-plate, so that the agent can stamp any output he likes upon it. It is well known that certain people in Australia do this kind of thing. For small machines the time specified for testing is frequently out of proportion to the importance of the apparatus. For example, motors of 5 and 10 H.P. are turned out by the hundred, and it may happen that twenty or thirty are wanted for one order. There is the choice between running all the machines for the full number of hours, or else picking out a given percentage, testing them fully, and assuming the rest are all right. When finding efficiencies, it is generally sufficient to find three points and then plot the rest of the curve. This method is generally accepted for efficiency, so why not accept the method for heating tests as well? Take the case of a number of direct-current dynamos. Thermometers could be placed on the field coils, and read off at intervals, and the temperatures plotted. If the heating curves are similar or below the curve obtained on a similar machine which has had the test prolonged to the full number of hours, then the machines may be considered to be satisfactory. At the end of each run the temperature of the armature can be taken, and if it is lower than the field coils, then all is well. If higher, then that circumstance would require consideration. In this connection it may be remembered that cable specifications frequently have a clause that the cable shall be kept under water for twenty-four or forty-eight hours. This not only means waste of time, but it is not effective, because a flaw which is at the bottom of the drum, and therefore has the hydraulic head of, say, 6 ft. of water over it, may be discovered, whereas the cable at the top of the drum is only a few inches under water, and the pressure is much less. The result has been that a great deal of cable is now tested by being placed in a drum which is filled with water and then subjected to considerable pressure. A flaw can thus be found in a few minutes that would escape detection the other way. Although mercury thermometers are usually employed, they are dangerous, because if a bulb should break the mercury may run amongst the coils. They are especially objectionable for high-tension windings; spirit thermometers are safer. An instrument for measuring temperature which has recently been introduced has a flexible tube of copper about the size of a No. 14 S.W.G. wire. The hole is filled with a liquid, and it communicates with a bulb of nickel containing saturated vapour; beyond which there is a pressure gauge. The fine copper tube is placed against the part to be examined, and being small and very flexible it can be placed in positions that are impossible for a thermometer.

The author's suggestion that 35° C. should be assumed to be the normal atmospheric temperature is very much to the point, because about 90 per cent. of the area of the British Empire has an average temperature well over 35° C. It is just an example of how insular we are that in all official tests we have adopted a figure that only suits this island. In hot climates it frequently happens that the machinery is only protected by a corrugated iron building, and the temperature

Mr. Scott. inside may be almost as high as it is outside. When the work of revision is taken in hand, it would be well to have some members who have lived in the Colonies and made a special study of the conditions there. It is interesting to note that the author refers to the coming of asbestos- and enamel-covered wires. About ten years ago I pointed out that enamel-covered wire would be the solution of many troubles, yet unmechanical cotton coverings still continue to be used. The right enamel does not appear to have been found as yet. It is said that the special lasting and elastic property of Japanese enamel is obtained by keeping it under sea-water for a long period. The matter might well receive attention by some electrical engineer in the East.

DISCUSSION BEFORE THE YORKSHIRE LOCAL SECTION, DECEMBER 6, 1911.

Mr. Emmott. Mr. WALTER EMMOTT: Some eighteen or twenty years ago we tried to get some system of standardisation of machinery, and also hoped to get some standardisation of selling prices, but after about a dozen meetings we came to the conclusion we could not agree, and so we gave it up. Something should be done as early as possible. Our competitors in Belgium, France, and Germany have had a lower standard of output and lower rating all the way through. If we have a British standard specification on the lines suggested the difficulty is gone. I find that the author's speeds, outputs, and sizes of machines agree pretty well with those of manufacturers with whom I, as a consultant, have no hesitation in placing orders. The proper thing is, as mentioned by Dr. Pohl, to run the machines right through the week. I would like to mention that if we get a proper system of standardisation it will have the result of sweeping off the market the men who cannot make a reliable machine to any specification whatever. It would also have the effect of reducing the work considerably when the quotations come in.

Mr. Wright Mr. H. H. WRIGHT: An organisation already exists which could undertake this question of standardisation, viz., the British Electrical and Allied Manufacturers' Association. I think it includes practically all the chief manufacturers of electrical machinery in this country, and they are the right people to do it. It is all very well for the Standardisation Committee to lay down certain lines, but unless all the manufacturers can be got to take it up it is worth nothing. In regard to the German specification as to the commutation of continuous-current machines, I agree with the author that it is too lenient. We have to design for good commutation on the most conservative lines. As regards the insulation referred to on page 183, I am glad to see that the author recommends a flash test of 1,500 volts as a maximum for line voltages not exceeding 500. I have noticed in many cases that 2,000 is specified. The extra voltage between 1,500 and 2,000 is likely to do more harm than good. Although the machine may actually stand a flash test of 2,000 I think there is danger of perforating the

Mr. Wright.

insulation. Then, of course, if there is such a weak place it may break down in working a few months afterwards. I have seen recently some particulars of an examination of these breakdowns under the microscope, and they showed that the press-spahn or other material has been penetrated with minute pin-points, but the centre of the compound insulation has generally withstood the test. I notice the author has not touched upon the question of standardisation of brushes. From the point of view of the station engineer, who may have a great many motors on hire, the question is of great importance. He may have a good many makes under his control, and if he had to keep two or three different sizes instead of twenty or thirty it would be an advantage. We are indebted to the author for his suggestions in regard to the time test. I do not think there would be any great benefit in reducing the period of test for small machines, but it might be an economy with larger sizes. At the same time I do not think, for mechanical reasons, it would be advisable to run a machine much less than five or six hours. With regard to the proposed standard speeds for motors and generators, this, of course, affords no great difficulty to the manufacturer, it simply means that he has to standardise a certain number of armature notchings and commutator sections. With reference to the table of speeds on page 199 of the paper, I would like to mention that centrifugal pump makers very often ask for an abnormally high speed, and I suggest that higher speeds be added to the table to answer their requirements. Fan makers frequently require an exact speed, because the power demanded by a fan goes up as the cube of the speed, consequently the speed of the motor for a coupled fan and motor must be very near to the correct one. I should think, however, there is enough choice in the speeds given to satisfy the usual requirements of fan makers.

Mr. Foster.

Mr. LLEWELLYN FOSTER: Following the headings as the author gives them, I quite agree with him that, now there are so many "intermittently" rated motors, it is essential there should be a subdivision of that particular class. The author does not specifically mention a "coal-cutter" motor; this is, of course, intermittently used, and, moreover, is subject to very severe strains; in my opinion it is quite wrongly rated at the present time. A few days ago I had occasion to make a test on a coal-cutter motor of standard make; it was run for three hours at its full-rated load, and its temperature rise was as follows: Armature, 152° F.; magnet coils, 151° F.; and the commutator, 98° F. As these figures were taken by a thermometer on the surface, it is certain that the inside of the windings was very hot indeed, probably very near the figure of 257° F., which the author mentions later on. The question of rating this class of machine is particularly important. I quite agree that the output of a motor for "intermittent" working should be the output at which, with suitable attention, it can work from week-end to week-end intermittently with the specified load factor; its suitability to be proved by the prescribed test. This load factor might, with advantage, be standardised as $\frac{1}{3}$, $\frac{1}{4}$, and $\frac{1}{6}$. With regard to the marking of output plates a good

Mr. Foster. example is set us by the larger firms, for example the British Thomson-Houston Company, and others who are careful to put as full information as possible on their plates; this plate is very often only marked to show the amperes and volts, the speed being frequently omitted altogether. All motors should be clearly marked to indicate whether intended for continuous or intermittent working, as this is by no means easy to find out. With regard to classification the author makes no special mention of the "pipe" ventilated class, which is rapidly coming into everyday use. Perhaps the author in his reply will kindly make this clear.

The figures for the wearing depth of commutators are high, unnecessarily so, as, if a machine does not spark, there is no reason why the commutator should not last as long as any other part. Emery cloth should never be used on any commutator; if glass-paper does not do what is required, then carborundum cloth should preferably be used. The peripheral speed will, of course, have a considerable bearing on the question of wear. We (the British Engine, Boiler, and Electrical Insurance Company, Ltd.) have a special clause in our specification with regard to performance, to which at first some makers took exception; but they have all come into line now, and this clause embodies all the points mentioned by the author, except that he suggests there should be practically no sparking. I would rather say no sparking, and also omit any reference to the brushes; these in my opinion should be fixed. On this point the French and German Standards seem to be too lenient, and there surely can be no necessity for the application of any glass-paper after a 24-hour run. I am afraid that consulting engineers are largely to blame for absurd requirements in regard to overload capacity. An overload capacity of 25 per cent., and even 50 per cent., is often called for; this must be quite unnecessary; if a lower machine is wanted, why not ask for it? We usually call for 25 per cent. for one hour, and 100 per cent. momentarily, which is amply sufficient for all practical purposes. I quite agree that full- and half-load figures are all that are really required; and this is also our standard practice with regard to efficiency and power factor. It is important that the method of ascertaining the efficiency should be clearly specified. A difficulty often crops up when it comes to the allowance to be made for loss in the brushes on the commutator or slip-rings; this again is a point on which we cannot always get makers to agree with us; there are two or three methods, but none of them is always quite certain. The author says in regard to insulation that no hygroscopical material such as cotton or paper should be employed, and I should like to know if the word paper includes press-spahn, etc., and whether this material is fully impregnated, as cotton and paper ought to be if employed. Is there any good reason why this substance is not nowadays used for intersegmental insulation; assuming that the voltage per segment is not excessive, there is no sparking, and oil is rigidly kept off the commutator?

We, as so many others have evidently done, have specified usually a maximum temperature rise, when measured by a thermometer on the surface, of 40° C., but always insist on a copper resistance test of the magnet coils both cold and hot, the mean temperature thus shown not to exceed 100° C. With regard to a temperature of 257° F., as a limit, I should like to know whether Dr. Pohl has made any experiments to ascertain if the insulation (such as is generally used in the construction of an armature) is not very dry and brittle. Thus, it seems to me, it must be in quite a short time if subjected to such a temperature or anywhere near it, more especially when it is remembered that in the case of an armature the material is always more or less under a strain owing to centrifugal force and the movement set up by expansion and contraction, which undoubtedly takes place. In connection with magnet coils, the author says it must be kept in mind in this connection that the inner portions of such coils exposed to 125° C., have only a very small potential difference between layers. This is quite true, but it is very essential that the insulation between the magnet coils and the frame should be as good as possible, and every care should be taken to make sure that no relative movement takes place between the wound coil and the pole. This is important when we remember that on all motors, for instance, connected to a 3-wire system, there is always one-half the supply voltage between copper and iron and so between the windings and the earthed frame, ready to break down the insulation. I notice that the author does not mention the motors of continuous-current turbo-generators, on which the field windings are subject to considerable stresses, and I am very doubtful whether it would be advisable to run them anywhere near the temperature figures mentioned. Mr. Foster.

I am quite in accord with the author regarding the proposed temperature of the surrounding atmosphere when making a test, and agree that the figure of 25° C., which we have all been using for some considerable time, might with advantage be increased to 35° C., and we would be prepared to adopt it in our specifications. One of our inspectors recently remarked that something might be done in the way of standardisation in arriving at a conclusion as to a suitable allowance for "watts per square inch dissipating surface," for partially and totally-enclosed machines. Most English makers, if they were asked regarding the heating of their machines, would no doubt say that the usual limit of 40° C. was not exceeded at rated output, but the difference in this respect, "watt's area" amongst different makers, is very noticeable. This, we think, is rather an important point, and I should like to know if the author has anything to say about it. Speaking to a large manufacturer to-day, I was informed that they allow 0·3 watt per square inch of total radiating surface—this for quite small machines. For larger machines over 5 k.w. and under 20 k.w., 0·45 to 0·5 watt if a fan is used on the armature—these figures to be multiplied by 2 if the machine is totally enclosed. For large machines, the usual figure appears to be 2 sq. in. per watt. Regarding the duration of tests, the

Mr. Foster. suggestion by the author is a good one, and we shall adopt it in our specifications if it is approved by the Standardising Committee. I should very much like to know to what temperature a machine or parts of a machine can safely be run when it is remembered that these parts are being revolved at a high speed and so subject to severe strains as I have previously mentioned. In connection with squirrel-cage rotors, I agree that, practically speaking, there is no need to work to a rigid temperature rise, unless ordinary soldered joints are employed, for which the approximate limit of safety appears to be about a temperature of 150° C.

Coming to No. 6, "Standardisation of pressures, frequencies, outputs, and speeds," this is perhaps the most important part of the paper, and the author, of course, speaks with considerable authority and from the point of view of the manufacturer. I am speaking from an entirely different point of view, but nothing would please me better than to see the machines properly standardised. I can safely say that in the large number of machines we have insured, there are machines of every conceivable voltage, and there really would appear to be no standard at all. We must, of course, remember that there are a great many private plants, and I think the number is not likely to lessen. Moreover, there seems to be a tendency for the voltage to become lower rather than higher, due to the adoption of the lower voltage metal filament lamps. We have certainly a great many more such plants at 50 and 30 volts now than we had a few years ago at 100 and 110. I agree with the author that the standard periodicity should be 40 cycles. The question of whether flickering is really noticeable on a 25-cycle supply has been raised before. Only last week, when in Glasgow, I noticed three big firms that had arc lamps and incandescent lamps connected to a power supply at 25 cycles, and practically no flickering could be seen. I am doubtful, therefore, whether it really makes the difference the author mentions. Regarding the standardisation of outputs and speeds, I am much interested in the author's suggestion, and consider this is a question that is best left in his hands. The suggestions appear to me to be very reasonable and workable.

Mr. Yerbury. Mr. H. E. YERBURY: To my mind standardisation stands for success not only in electrical engineering but in many other industries, and it would be a good thing if standardisation on the lines suggested by the author could become universal. I should like to go a step further and suggest that it would certainly be to the advantage of the user if some standard could be framed and adopted for the mechanical as well as the electrical design of machines. For instance, it has been my unfortunate experience to have machines installed for continuous running, where the bearings are so hot that the hand cannot be placed upon them. This is attributable solely to bad design, and I suggest that a standard ratio of bearing surface to diameter of shaft could readily be adopted. I agree that there are many engineers unfamiliar with the existing standards, and it is regrettable to find that some

manufacturers ignore the British Standard Specifications, even when specified by engineers. Needless to say, whatever standards are adopted, excellence of design and efficiency will still be the predominant factors when orders are being placed. Mr. Yerbury.

The author's remarks concerning temperature rise and methods of taking same are extremely important, and his suggestion of an internal thermometer strikes me as being more suitable for general use than the resistance method. It is well known that high internal temperature is the cause of many breakdowns of field coils, and I can support the author in saying that external temperature readings are both unscientific and misleading. I observe that the Germans wisely have different ratings for different coverings. These prove in practice to be well founded. I may say that many years ago we experimented with asbestos-covered wires for motor field coils, and the results proved so satisfactory that it is now our standard. These coils, of course, are unimpregnated, and they can be worked at a very high temperature without disastrous results. Now that the majority of manufacturers use commutating poles, I see no reason why standards could not be adopted for open and enclosed type motors as suggested.

Mr. W. HARTNELL : With regard to classification, I do not see the advantage of including such specialities as flame-proof motors. Some twenty years ago I patented an explosion-proof motor, and at the same time I patented a ventilated motor, divided by a diaphragm into two parts forming a suction and delivery (with or without external pipes). For ventilation in explosive atmospheres it was proposed to pass the air through an external entirely closed cooling chamber. The thickness of the commutator segments must not only be sufficient for reasonable wear, but sufficient to leave a margin of transverse strength when the commutator is worn out. The question of overload capacity from a commercial point of view seems to have been forgotten by the scientific men, but not by the author. No manufacturer wants a motor except as a necessary means to an end. In these competitive times the business man wants to pay a minimum price for the power he has decided to be necessary. The manufacturer should be offered what he demands with a nominal margin. In years gone by engines and boilers were expected to carry heavy overloads. At the present time it is usual to tender definitely for the stated horse-power of the engine, and the gallons of water evaporated per hour by the boiler under certain definite and advantageous working conditions. In the competition of the nations our foreign friends have an advantage because they specify and make motors to do the working load named, but not to do much more. If we get an inquiry from Japan or South Africa, and we use the English specification the chances are that they only perceive that we are dearer than Europe or America. If we are to compete in the business of the world we must be somewhere in line with the Continental markets. Mr. Hartnell.

With reference to the temperature rise, the limits must in practice vary with the conditions of service. In central stations and on board

Mr. Hartnell.

ship there must be no risks. In, say, a steel works where there are more than a hundred motors, it may be good business policy to allow much higher temperature limits. From many years experience with repairs of various makes of dynamos and motors, I conclude that the failure of a shunt coil from high internal temperature under ordinary working conditions is very rare. Safety and safe limits in electrical plants, must in the end be determined by experience. If the insurance companies who insure dynamos, motors, etc., would undertake thorough inspection and tests at reasonable intervals and record all failures (as is being done in regard to steam engines, etc.), a mass of statistical evidence would be obtained on which to base the most advantageous practical limits of and standards for electrical machinery.

Mr. French.

Mr. W. E. French: I think we all agree that one-hour test for intermittent working is not a proper test at all. Any one who has dealt with the testing of motors for intermittent service or traction work will agree with the author that the machine thus tested is far too big for the purpose. With regard to classification, and particularly to the introduction by the author, of flame-proof machines, the adoption of standards appears somewhat premature. I have investigated this point in conjunction with Mr. Bowen of the Mining Department of the Leeds University. We have made inquiries by circular letter to most of the prominent manufacturers of this country, and we find that in very few instances have any reliable tests been made by the manufacturers when adopting the flame-proofing on their machines and apparatus, and where it has been adopted they have done so entirely on the German basis. We find that the German tests which have been carried out in Bochum, although classic, were incomplete, and need further extensive experimental investigation and verification. They first of all completely omit one very important point, viz., that all the tests have been carried out entirely in still atmosphere and not in the presence of coal-dust. Coal-dust will tend to fire lower percentages of gas mixtures; the hot gases will therefore be under lower pressures in the motors and apparatus, and leave the motors by way of the safety devices at the lower velocity, hence the apparatus will not be so "flame proof" in these surroundings mentioned, as "velocity cooling" and expansion cooling play an important part. If we are to be guided by our experience on safety lamps, the velocity of the surrounding atmosphere has a bearing on the action of the lamps, and as we invariably have to deal with considerable velocities in mines, it is very likely that apparatus found safe in the German tests may fail in the experiments we shall shortly be conducting. Therefore I think this point should be taken up with some caution, and we must have some further tests and conclusive practical evidence before establishing a standard.

With regard to sparklessness, that is a question, I think, that it should also be attempted to standardise. What is dangerous sparking and what is not is largely a point of controversy. What some men will consider a certain amount of sparking other people will consider

extremely bad. I have here a list of terms which have been adopted to overcome this difficulty, and I think it answers admirably. In order to get to some standard we used various terms stating various degrees of sparking with figures at the side of the description corresponding to certain descriptions of sparking. Mr. French.

For example :—

A. Sparkless.
B. Very slight sparking.
(A line of small pin-points all along brushes; does no damage and does not affect commutator.)
C. Moderate sparking.
(A few bright sparks like pin-heads visible in daylight; commutator blackens; sparking thus becomes injurious after a long time.)
D. Bad sparking.
(White continuous sparks along the brushes; noisy, occasional long snaps; commutator lugs appear stationary and brightly lighted up. Commutator segments gradually pit and heat.)
E. Dangerous sparking.
(Makes a loud cracking noise, consumes brushes, and may fire from brush to brush. Commutator pits rapidly.)

Something of this kind should be included in standard specifications in order that we might know what would be acceptable.

Another point on which I am afraid I cannot agree is the German specification with regard to shift of brushes. I do not agree with the first part, but I think the second part is fair and acceptable, viz., that they limit the outputs of a machine for which the brush position is to remain unaltered from quarter load to full load, and that is all that need reasonably be expected from a machine. That the brush should remain untouched I think is entirely on the supposition that commutating poles will be used. Even if machines are designed with a liberal reactance voltage, that is, a low one, and even with a good stiffness of field, I have found it has been very difficult to adjust the brushes so that they will run sparkless from no load to full load. Often if we adjusted the brushes at no load the brushes would certainly spark at full load, and *vice versâ*. I therefore feel that we should be inclined to adopt that reservation with regard to the brush adopted by the Germans. With regard to insulation, I would like to say that the machine should be tested hot, or at its final temperature. One minute is a somewhat long time; half that is sufficient to show any defects in the insulation; any longer periods only tend to weaken the insulation unnecessarily. In the alternating-current system twice the voltage of the amplitude waves for the flash test might meet the case. Should there not also be an attempt made to standardise the frequency for traction? Within the next few years I should think that serious attempts will be made to introduce alternating-current traction on a

Mr. French. large scale. The frequencies will have to be low, especially with rail return, on account of the "skin effect" in the latter. I can only admire the way in which the author has made out his scheme and tables of speeds, etc. I think they are excellent and meet the designer's view to the fullest extent; at the same time they give the users a very free choice in speeds and outputs. I should like to ask why Dr. Pohl has not introduced the overload capacities of induction motors.

Dr. Pohl. Dr. POHL: I intended them to apply.

Mr. Churton. Mr. T. HARDING CHURTON: The first step that is necessary in order to bring about general standardisation of electrical machinery is a reduction as far as possible in the variety of electrical supply system. In continuous-current systems many different voltages are met with, and in alternating current the manufacturer is faced with single-, 2-, and 3-phase as well as numerous varieties of frequency and voltage. In recent years we have witnessed some important changes even in large installations. In Leeds the system originally put down principally for lighting was single-phase 83 cycles, but with the advent of the polyphase motor Mr. Dickinson took time by the forelock, and changed over to 2-phase 50 cycles. At Huddersfield the electric supply was until recently single-phase 100 cycles, and this has been, I believe, superseded by 3-phase 50 cycles. There are, however, large power schemes operating at 25, 40, and 60 cycles, and so on, and so great a variety of electrical supply is unfavourable to the production for stock of machinery such as motors. One difficulty in the way of the adoption of certain standard outputs for motors is that it might tend to impede progress in the design and manufacture of such machines. For example, a motor that at present gives 10 B.H.P. under certain conditions, might, by the use of improved material or ventilation, be made to develop 11 or 12 H.P. Why should the manufacturer be precluded from rating the motor at its true value in the event of this not happening to correspond with an arbitrary standard? I would venture to suggest that it is the most urgent duty of the Engineering Standards Committee, or of this Institution, to take in hand the revision of the report on the rating and testing of electrical machinery, already too long delayed.

Mr. Conder. Mr. EUSTACE R. CONDER (*communicated*): There is just one question which I should have liked to have asked the author to reply to. On page 183 he suggests a flash test to earth of double the working pressure. He, however, does not mention a flash test between phase windings in alternating-current machines. I should be glad to know if that omission is accidental or intentional, and if intentional, what are the author's objections to such test? I consider a flash test between phases very desirable, because it is not uncommon for the insulation to break down between phase windings. I have noticed that some reputable makers put less insulation between phases than to earth. Yet with the system completely insulated or the neutral-point earthed there is a greater pressure between phase windings than to earth.

Dr. Pohl.

Dr. POHL (*in reply*): Let me say at the outset that I have been delighted with the amount of criticism my paper has received and the large number of further suggestions which have been made. The main object of the paper has thus been attained. It is only by criticising and by discussing alternatives that we can supply to the Standards Committee the material from which to formulate the new rules to which we are looking forward.

I wish, in the first place, to reply to Mr. Hammond and to clear myself from the charge of having attacked the constitution of the Standards Committee. One speaker even thought that I had made scathing remarks about its members. Needless to say, no such idea entered my mind; on the contrary, I cordially agree with the constitution of the sub-committee which formulated the standards of 1907, and have clearly pointed out that I would like to see the standards developed by a committee constituted on similar lines. It is for this very reason that I brought this paper forward here and not before the Association of Manufacturers, because any standards brought out by the Manufacturers' Association would not be backed up by the authority of a competent and independent body representing all the interests involved in this question. What I have stated, however, and what I maintain is, that the standards of 1907 represent the first and tentative step in the direction of standardisation and have in practice proved a complete failure. This latter fact was borne out by several speakers, and it cannot be denied. I will go further and say that other manufacturers complain with me that nothing further has been done since 1907, though most of them appear to be afraid to come forward and to stand here to be shot at. I am afraid Mr. Hammond has misunderstood one or two suggestions which I made. In the first place, he thought that if my proposal with regard to the duration of tests were adopted he would have to go with his wife and family to the particular place and stay there at least "from week-end to week-end." Now I have specially introduced a clause, which I read to you before, the intention of which was not to lengthen, but to shorten, the duration of the test in most cases, because I believe the 6-hours' test is too long for the majority of machines, namely, the small and medium-sized machines, while it is too short for the larger ones. I clearly stated that "the suitability for running from week-end to week-end shall be proved by the prescribed tests." Those prescribed tests, of course, do not include a run from week-end to week end, which would be absurd. Mr. Hammond also suggested that the committee had swept away the overload. While I was in perfect agreement with the spirit of his remarks on that point, I am afraid the committee have actually not swept away the overload. The fact of the matter remains, as pointed out before, that 25 per cent. overload for two hours and 50 per cent. for half an hour is almost general British practice. This has not been affected by the committee leaving out any clause relating to overload from the specification. Mr. Hammond further criticised my suggestion of replacing 25° C. by 35° C. as

Dr. Pohl. the basis of the temperature specification. I believe this is a matter of considerable importance, and my suggestion was fully approved of by other speakers. Mr. Hammond pointed out—and I was well aware of it—that the present standards allow a reduction or an increase of the permissible rise according to whether the temperature of the atmosphere in which the machine will have to work is below or above 25°. But this means that machines intended for use in an atmosphere above 25° C. require to be designed specially, and it is this special design I desired to see avoided. That is the meaning of the suggestion that the standard figures for temperature rise be based on an atmospheric temperature not of 25° C. but of 35° C.

Mr. Churton pointed out, and I agree with him, that one cannot standardise alternating-current machines for all the frequencies prevailing in this country. I only suggested they should be standardised for 50 and 40 cycles. It is a very unfortunate circumstance that we have in this country so many frequencies, and this is due to the fact that we started standardising too late. If we had standardised voltages and frequencies early enough we should not now be faced with these difficulties. But surely that is no reason why we should not learn from our mistakes, prevent the further development in these multifarious directions, and standardise machines at least for the most common frequencies.

Mr. Robson is of opinion that the number of sizes which I have given in Table IV. is too great. [Mr. Robson: No. I say they are greater than what the average manufacturer gives to-day.] I did not like to make it any smaller because, as pointed out in the paper, the number of sizes determines the speed steps, which latter must not become too great. Even with the standards suggested the speed steps are 33 per cent., and after careful consideration I came to the conclusion that we should not go beyond that. Mr. Robson thinks that unless manufacturers come to an understanding as regards selling prices we shall never be able to make profits. Whilst I fully agree with many of his reflections this is a point on which I disagree. In my opinion the prices of machines as sold in this country correspond to those at which they are sold in the open market of the world—in other words, they are to a large extent determined, I believe, by the price at which foreign-made machines are offered. It is frequently stated that selling prices are too low for manufacturers to make reasonable profits. But what I say is that our manufacturing costs are too high. We must learn from the methods of industrial organisation adopted abroad and bring our manufacturing costs down. By doing so we shall make profits because selling prices will not decrease in the same proportion, and our balance-sheets will look very much healthier at the end of the year. I do not believe in artificial means of raising manufacturers' profits by various legal, political, and other methods which have been suggested. I would not like to do away with the sting of either home or foreign competition, and thus to hide away our own weakness. We should learn by it and try to find out why those

people can obviously make good profits in spite of low selling prices. It is not because the machines are bad, that is quite an exception. The fact is that, aided by standardisation, they have developed a higher form of industrial organisation, which means higher industrial efficiency. They manufacture in large numbers, whilst we continue to make individual machines. Instead of waiting for manufacturers to form a ring amongst themselves it would be very much better for all concerned, but especially for the general buying public, if an independent body, such as the Institution or the British Standards Committee, would take the first step in this matter and, by standardising not only performances, but also outputs and speeds, give small and large firms some of the advantages which the great American and German concerns derive from their organisation and vast production. Dr. Pohl.

Dr. Thompson very rightly drew attention to the increasing demand for 115-volt machines for private installations. Nevertheless, the number of 115-volt dynamos made at the present time bears such a very small proportion to the total number of motors and dynamos manufactured that I considered myself justified in suggesting their elimination from the list of "standard" machines. The provision of 100- to 115-volt machines means a serious complication with regard to the length of commutators, length of end-shields, and so on. I think for the present they should remain special machines, but if the development of the 115-volt supply continues they would, of course, later on be included in the standards. Dr. Thompson also drew attention to the misleading term "regulation." It should be "irregulation," of course. I adhered to the word "regulation" because it is contained in all the standards. He gave us a very interesting and very useful rule for determining how long it will take for a machine to reach its final temperature. [Dr. THOMPSON: Not how long—how high it will go. May I explain? The rule I gave was not how long it will take to get up to the top, but what is the top to which it will go up. The test goes on long enough for the rate at which the temperature is going up to have become half what it was at starting; then, being half-way up to the top, we have only got to double the reading and we have it.] The object of the application of that method, I take it, would be to reduce the duration of tests. [Dr. THOMPSON: Exactly.] Mr. Jones pointed out a fact, of which I was fully aware, that manufacturers had ample opportunity in 1903–4 for suggesting to the Standards Committee what was desirable, and no doubt the standards which were the outcome of those considerations were made in conjunction with the manufacturers. But a Standards Committee should be a standing committee to which any development in manufacture should be immediately referred, so as to keep the standards up to the requirements of the time.* Mr. Jones also raised the very interesting question as to what "no sparking" means. I am quite in agree-

* Through the courtesy of Mr. L. S. Robertson, Secretary of the British Standards Committee, I have since been informed that the various sub-committees annually meet to reconsider the reports issued, so that this point is fully met.

Dr. Pohl. ment with him that it would be very much better if we could get some accurate definition of that condition. I believe if one sets about it very carefully, one can always detect some sparking in every machine. Even if it is not visible there will probably be some minute sparking under the brush in the majority of cases. For this reason I object to the term "absolutely no sparking." We must arrive at some understanding about this question. What I meant by practically no sparking was, that there should be no sparking which will in any way injure the surface of the commutator, even if the machine continues to run for weeks. This, I consider is the determining feature, though a practical definition will require very careful consideration. I cannot go into all the questions raised in the discussion; I will communicate them later, but I hope, and from one remark which Mr. Hammond made, I believe, that our suggestions will be useful for the formulation of new standards. I think Mr. Hammond indicated that the committee will shortly meet again to consider this matter, and if our discussion to-night will have any influence on the deliberations of that committee, then I am quite sure my paper and the discussion to-night have not been wasted, but that we have done useful work, directly or indirectly, for the benefit of all sections of the electrical industry.

That Mr. Emmott as a consulting engineer is so fully in agreement with the proposals which I put forward is a matter of great satisfaction to me. I was somewhat afraid that consulting engineers might look askance at the suggested thorough standardisation, which, of course, means some curtailment of individual views. I was confident, however, that consulting engineers would ultimately agree that the adoption of standards which have been evolved by the consideration of a representative body such as this Institution or the British Standards Committee is in the interest of all parties concerned. Mr. Emmott's remarks fully bear this out. It need hardly be mentioned that the standard specification requires to be amplified in the case of all special machines.

I doubt whether Mr. Wright's suggestion that the size of brushes should be standardised is a good one. I am particularly anxious to avoid standardisation where it may impede progress, and for this reason I also disagree with the suggestion of standardising mechanical parts. Mr. Wright drew attention to the high speed required for driving centrifugal pumps. I consider that motors for these purposes are really special machines, and need not be considered in lists of standard machines, at any rate for the present.

I was particularly glad to receive Mr. Foster's approval of many of my suggestions. He mentioned that I have not included pipe-ventilated motors in the classification of machines. I intended that these motors should come under the class of ventilated machines, there being little difference between a modern "ventilated" and a "pipe-ventilated" motor. As regards overload capacity, Mr. Foster is one of few engineers who realise the absurdity of the excessive requirements still to be found in most British specifications. Mr. Hartnell pointed out

very clearly that what is wanted is a motor to do certain work and that it is foolish to specify, say, 25 per cent. overload for a great length of time or even continually. If we want a 10-H.P. motor to run at 20 per cent. overload continuously, we might as well call it a 12-H.P. machine. Mr. Foster suggested that the word "practically" in the "sparking" clause should be eliminated, in order that it might read "there shall be no sparking." Frequently the words "absolutely no sparking" are employed, but there is nothing "absolute" in this world. I am, however, fully in agreement with what Mr. Foster meant to convey. No sparking should be permitted which would prevent the commutator from forming and maintaining a bright surface. He also objected to the clause that there should be no shifting of the brushes, "except where otherwise stated." The object of the latter reservation is merely to take into account machines intended to be regulated by means of shifting the brushes; in other words, it should apply only where it is an understood point at the time of placing the contract that the brushes are to be shifted. Dr. Pohl.

This brings me to a point which Mr. French raised. He suggested that we should adopt the German rule, *i.e.*, that the brush position should remain fixed from ¼ load to full load only, in view of the difficulty of designing machines for constant brush-position throughout. I quite agree with Mr. French's statement that it is very difficult to get this constant brush-position without interpoles, but nowadays it is out of the question to expect people to move the brushes when the load comes on. Where it is not wished to employ commutating poles, there is no alternative but to use a larger machine. I am obliged to Mr. Conder for raising the question of the flash test between phases of alternating-current machines. In my view the flash pressure to earth should also apply between phases where these phases are insulated from one another under working conditions: for instance, in the case of 2-phase windings. For theoretical and practical reasons, however, a different test should apply for windings permanently joined at one or more points, such as 3-phase windings. For such machines I suggest that an insulation test between phases might be carried out by raising the speed and over-exciting the field so as to obtain a pressure between the terminals 50 per cent. above the highest working pressure.

Mr. Foster drew attention to the difficulty of measuring the drop in brushes. It was for this reason that I suggested the Standards Committee should fix definitely the voltage drop which has to be taken into account in working out the efficiency, and that for this purpose brushes should be divided into three classes: carbon, metal carbon, and metal brushes. With reference to Mr. Foster's objection to the maximum internal temperature, which I gave as 125° C., I suggested this figure only for the internal parts of field coils, whereas for the internal parts of the windings, which are subjected to high mechanical and electrical stresses, I suggested 110° C. Of course, I am well aware that insulating material deteriorates gradually; that is proved con-

Dr. Pohl. clusively by the experiments carried out at the National Physical Laboratory, but 125° C. is the temperature which was found to be the safe limit for cotton. According to my suggestion, this temperature would only be approached in the central parts of field coils where we have not to deal with press-spahn but only with cotton. In all modern machines the field coils are thoroughly impregnated after being dried in vacuum, which makes them capable of standing a higher temperature than ordinary cotton. I am therefore certain this specification is quite safe, considering also that the external parts of the coils, where we have press-spahn and other insulating materials, will, of course, always be at a much lower temperature. There are numerous machines, the field coils of which have an internal temperature above 125° C., which have been running for twenty years or more and continue to give entire satisfaction. This proves conclusively that the internal temperature suggested is within the limits of safety.

I am very glad to hear that Mr. Foster has already issued instructions for the adoption of the internal thermometer test. It will be interesting to find out how it works in practice. I was somewhat surprised at his statement that metal filament lamps do not flicker at 25 cycles. I noticed that the L. B. and S. C. Railway, which is operated by 25-cycle current, have adopted metal filament lamps in some carriages, and was surprised at the flicker, which was most disagreeable. I noticed also other coaches which were lighted by carbon lamps, and there was no flicker. That is quite in agreement with a test I carried out some eighteen months ago.

Mr. French's experiments with regard to flame-proof motors will be most valuable, and I am glad he has given us some preliminary results. His statements as to the effects of carbon dust on the explosion pressure were most interesting; they confirm the view I have held all along, that the long-joint type of flame-proof motor is greatly superior as regards safety to the grid type.

Mr. Churton is afraid that the adoption of standard outputs might tend to impede progress, in so far as it would prevent manufacturers from taking advantage of such improvements as would allow the output to be raised by only 10 or 20 per cent. This objection is hardly a valid one, because the raising of the output is by no means the only way in which manufacturers can utilise minor improvements. Another way consists in the saving of material or labour and thus in the cheapening of production, and perhaps the best way of all is the improvement of the running qualities. It is fallacy to believe that standardisation of outputs and minimum performance means stagnation. I would oppose it strenuously if I thought there was any real danger in that respect.

(*Communicated*): Several speakers expressed the view that it is too early for the inclusion of the flame-proof motor in the standards. I think that, on the contrary, definite explosion tests ought to have been prescribed long ago for all machines and apparatus sold as flame-proof. If the Institution had attended to this important matter as well as to the question of the "competent" colliery electrician in the way the Associa-

tion of Mining Electrical Engineers is now doing, there would have been no cause for the scare as to the use of electricity in mines which has been reflected in recent legislation. Even one or two of the speakers appear to have been affected by that scare. It should be clearly recognised, however, that the saving of human lives quite apart from the economic aspect, which is the indirect result of the use of labour-saving electrical appliances in mines, must be infinitely greater than the number of fatal electrical accidents ; the statistics show these latter to be surprisingly few. Electric machines for use in mines can be made as safe as miners' safety lamps, and there is no need for any special restrictions, provided that stringent tests are insisted upon to demonstrate that they are really flame-proof. Dr. Pohl.

With regard to the duration of temperature tests, whilst some speakers suggested methods for reducing them even more than I advocated, others prefer to adhere to the 6-hour run which they consider a good mechanical test. In my experience a mechanical defect which does not show itself during the time it takes for the machine to approach its final temperature—and that is my proposal—is not likely to be found out within another hour or two. Moreover, there is the overload test which represents a much more severe mechanical trial than would be obtained by a continuation of the full-load run beyond the time required for heating pure and simple. For these reasons I must uphold my original proposal. Mr. Jones objected to the internal temperature of 125° C. for field coils, because of the large speed variations between cold and hot, which he believes it would lead to. Now this view appears to me to be erroneous. In the first place, I have pointed out in the paper that 125° C. internally is often reached and exceeded under the rule of 40° C. rise of the surface. But quite apart from that, where a low speed variation is desired it can be obtained by a suitable choice of the magnetic densities, even if the proposed rule were to affect seriously the rise in resistance of the field coils, which it would not do.

I am greatly obliged to Mr. Cooper and to Mr. K. Scott for their contributions, and also wish to associate myself with Mr. James' remarks as to the need for standardising voltages and frequencies for single-phase traction. He further pointed out that the proposed internal thermometer test would be difficult to carry out in many cases of enclosed or protected type machines. I was not unaware of this difficulty, but consider that a small hole might easily be drilled into the frame or end-plate to facilitate the insertion of a thermometer where this is not otherwise possible. Alternatively a flexible thermometer might be employed, the simplest form of which is probably a thermocouple, which would permit of the temperature rise being directly read from a suitably calibrated millivoltmeter.

In conclusion, I wish to return to the larger aspect of the problem of standardisation. How great is the benefit that can be derived from it ? Mr. Robson gave it as his opinion that the reduction in the cost of manufacture would not be as great as might be anticipated unless manufacturers agreed on a scheme of pooling and suitably distributing

Dr. Pohl. their orders. In my view Mr. Robson has, with these remarks, indicated the key to the whole situation. For years I have been of opinion that such a scheme of co-operation, which would immediately result in much lower cost of production, is not only from every point of view the most desirable, but also the most probable outcome of the industrial developments in this country. I estimate it would first of all mean a reduction in cost of as much as 25 per cent. Those who doubt this may enquire whether any manufacturer would decline an order for, say, a thousand 20-H.P. 440-volt motors to comply with a safe specification such as outlined in my paper, at 25 per cent. below his ordinary selling prices, when there is, moreover, a practical certainty of regular repeat orders. The bulk of this saving would benefit the consumer, and the reduced prices would give a powerful impetus to our export trade and further accelerate the electrification of industries in this country and abroad. The pooling of orders could not without very great difficulties apply to anything but standard machines. Yet it is a well-known experience that with almost every large installation, special machinery is required as well as standard, and the demand for the former is therefore bound to go up as well as the latter. The scheme of co-operation outlined above represents in my view the healthy and desirable equivalent for trusts and secret combines, and considering the low cost of raw materials and low cost of living resulting in a satisfactory level of wages, I see no reason why the British electrical industry should not develop into an exporting industry of the first magnitude, and why all the establishments, the total capacity of which is at present quite excessive, should not be kept fully, regularly, and profitably employed. It will probably take years, however, before the manufacturers will have become sufficiently educated to fall in with some such scheme of co-operation. At present most of them still think that the only way of getting orders is to take them away from their competitors. Nevertheless, co-operation for the economical production of standard machines is bound ultimately to take the place of wasteful competition. There can be no antagonism towards it, because the prosperity of all sections of the electrical industry is bound up with that of the manufacturers. It is because I foresee this development that I have laid so much stress on the need for an independent and representative body drawing up not only a minimum standard of performance, but in addition a complete list of standard outputs and speeds.

SMALL ELECTRICITY SUPPLY UNDERTAKINGS.

By Percy A. Spalding, Associate Member.

(*Paper first received July* 29, 1911, *received in final form October* 30, 1911, *and read before the* Dublin Local Section *on December* 7, 1911.)

Slightly more than eight years ago a paper was read before the Leeds Local Section by Mr. A. B. Mountain* on the subject of the supply of electricity to small towns and villages.

The subsequent progress of supply in small areas has, however, been very disappointing, and the author is of opinion that the subject is well worthy of further consideration under the improved conditions which now obtain.

In the first place, suction gas plants and engines are very much cheaper, and are more economical and reliable in operation than in earlier years; secondly, the advent of the metallic filament lamp had reduced the cost of electricity to the consumer to about one-third of the cost heretofore, light for light; so that even the poorer classes (which form a large percentage of the population in small areas) now find it cheaper to adopt electricity. Further, the initial capital expenditure required to establish a supply in a small district is very much less, for the reason that not only, as has already been stated, are generating plants cheaper, but also the capital expenditure on mains is less. Lastly, the cost of producing electricity by modern suction gas or Diesel oil engine plants is reduced to a figure which would, a few years ago, have been considered impossible with very small plants.

These important facts go to prove that the prospects of success with such undertakings are considerably improved and should be the means of stirring up local enterprise to a greater extent than has been developed during the past few years.

Keeping in view, however, the fact that the same amount of light as was hitherto obtainable can now be had at about one-third of the cost to the consumer, it is reasonable to assume that the demand for light will now be correspondingly greater, and therefore the revenue during the early years of the undertaking will also be increased, although perhaps not in the same proportion as the demand.

In comparison with the conditions which existed in earlier years,

* *Journal of the Institution of Electrical Engineers*, vol. 32, p. 1017, 1903.

the following specify those that now obtain, and which, it is expected, will be the means of accelerating local enterprise:—

1. Reduced capital expenditure on plant and mains; and therefore
2. Reduction in the amount of the annual repayment of loans.
3. Reduced working costs owing to more economical generating plant.
4. Increased output due to greater demand for cheaper light.
5. Increased profits as represented by the difference between (3) and (4).

It is the ambition of each of some of the larger supply companies to control as extensive an area as possible, and to supply in bulk all the small towns and villages that are within this area. Under present conditions, however, electricity can now be generated locally at a price against which the large supply company will find it hard to compete.

The scope of this paper is limited to very small towns having a population of from 1,000 to 5,000, and to larger towns having a population from 5,000 to 15,000. The conditions which govern the supply vary so greatly between these extremes that the author considers it advisable to subdivide his remarks under two headings.

Case I.—Smaller Areas, Population 1,000–5,000.

Plant and Buildings.—There are very few districts in the United Kingdom where it will be found possible to supply electricity from water-power, which can be harnessed at a reasonable cost. Assuming that in a particular case a water supply is conveniently near, and that careful investigations show that during the driest season of any year there will always be sufficient supply of water to drive the proposed plant and meet all demands, the question which then must be considered is whether the running costs and standing charges for a hydro-electric plant will be more or less than similar figures estimated for a suction gas or oil engine plant.

The question of prime movers for these small plants (other than water turbines) will, as a general rule, have to be decided between suction gas plants and oil engines working on the Diesel principle. The generating costs per unit with the respective plants will depend largely upon the price of fuel per ton delivered at the station.

The capital cost of a suction gas plant is less than that of a Diesel plant of the same output, but against this must be considered the fact that repairs and depreciation are greater with the former. All things considered, however, there can be no question that for these very small districts, where the capacity of the plant does not exceed 100 B.H.P., suction gas engines at present take precedence over all other existing prime movers.

(Further remarks on this question will be made later.)

A battery of accumulators is absolutely indispensable with these

small undertakings; the many advantages attendant with a battery will more than compensate for the capital expenditure on it. Accumulators as now manufactured require very little attention, give no trouble, and, so far as maintenance is concerned, it is sufficient to state that the makers, as a rule, will enter into a contract for a long period, and maintain the battery at its rated efficiency during this period, at an annual charge of about 7½ per cent. of the initial cost.

The author makes no attempt to quote any estimated figures showing the capital expenditure required for any particular scheme, either here or later, as he considers that such would serve no useful purpose. Accurate and reliable figures can be determined only when full details of local conditions, which may have any bearing whatsoever on the undertaking, have been carefully ascertained.

Supply, and Distribution.—In the majority of these areas a direct-current 220-volt 2-wire system of distribution will probably be found the most satisfactory, all things considered. In certain cases, where the area of the district to be supplied is very small, it will be worth while to estimate whether, if the distribution pressure were only 110 volts, the increased cost of copper in the mains, as compared with a 220-volt system, will be more or less than the extra cost of a battery having twice as many cells of smaller capacity, as would be necessary with the higher pressure. Also with the lower pressure it is worth while to consider the question of using bare copper tubes or strips for the feeders instead of insulated cables.

As regards the method of installing the mains, it should be remembered that in most of these thinly populated areas the houses are very scattered, and in consequence the distributing system will be comparatively extensive. In such cases underground mains will be so costly that, from the commencement of the supply, a serious handicap is imposed on the profitable working of a small undertaking owing to the increased capital expenditure on mains. Every effort therefore should be made to obtain permission for the erection of overhead mains. The advantages of an overhead system over underground mains are well known, but it may not be out of place briefly to enumerate them here:—

1. Initial cost of complete system only about one-half of that of an underground system.
2. Cost of service mains correspondingly less.
3. Extensions carried out more expeditiously and at considerably less expense.
4. Easier to inspect and keep in order.
5. Repairs and maintenance less costly.

Charges for Supply.—The majority of the houses in these districts are small, and the number of lights required will seldom exceed 6; the round average for a number of such houses may be assumed as 4 lights. In these cases it will well pay the undertakers to supply small

consumers at a fixed contract rate per annum, based on the sizes of the lamps in use and the probable burning hours. This system has the important advantage that meters can be dispensed with, so effecting a corresponding reduction in initial expenditure; and there is a further saving in working costs, in that the expenses connected with attention and repairs to meters is avoided, and clerical work in reading meters and making up accounts is correspondingly reduced.

(The question of charging for current is discussed at greater length later on.)

The working costs per unit generated with the smallest of these plants should not exceed 1·5d., while the total costs, including all standing charges, could be kept at or below 2¼d. per unit, provided the initial capital expenditure is small. If, therefore, a flat rate tariff is fixed at 6d. per unit, it will enable the undertaking to make a good profit on the sale of current, and should meet with the general approval in the district. At this price the cost of burning a 16-c.p. metal lamp for 1,000 hours will be 9s. This size of lamp will probably be generally used in these small houses, and as the inhabitants usually keep early hours, the average burning hours for each lamp installed might reasonably be taken as 1,000 per annum. Hence, the contract charge can be fixed at 9s. per 16-c.p. metal lamp per annum. The generating costs for every 100 such lamps connected will be about £6 10s. per annum. To this must be added: (1) Distribution costs; (2) rent, rates, and taxes; (3) management expenses and special charges; and (4) proportion of loan repayment and interest on capital, or depreciation and reserve, according as the undertaking is run by a local authority or by a company. The gross profit, after allowing for items (1), (2), and (3), will be about £30 per annum for every 100 such lamps connected. It is obvious, therefore, that the greater the number of lamps connected, and the sooner they are supplied, the greater will be the prospect of the undertaking showing a net profit during the earlier years of operation.

It is suggested above that 6d. per unit will form the basis on which the contract charge per lamp is fixed. The actual figure in any particular case will depend, of course, upon the standing charges per kilowatt of consumer's demand and the running costs per unit, and therefore can only be determined with any degree of accuracy after the station has been in operation for at least two years. The preliminary figure charged, however, should err, if anything, on the high side; it can then be reduced accordingly as more accurate figures are obtainable.

It is scarcely to be expected that a contract supply can ever be universally adopted in any particular district. There may be a number of large houses, residential or otherwise, the owners of which will prefer paying either by meter at the rate of, say, 6d. per unit, or by whatever alternative tariff is in force. In some cases, where, for instance, as many as 20 lights or even more are installed, and the owner will consider the question of a contract, but not on the basis of 9s. for every equivalent 16-c.p. metal lamp connected,

it will be found necessary to readjust the charges according to the number and sizes of the lamps installed, and to the extent to which these will be used.

It should not be a difficult matter to fix an equitable charge of a lump sum per annum to cover all the lights installed. During the past two years the author has drawn up agreements for a supply by contract to a number of comparatively large buildings of all classes, in which are installed lights varying in number from 30 to 75, equivalent 35-watt metal lamps. The author sees no reason why this contract system could not be applied with equal facility and advantage, to cover a supply to small domestic utensils, such as electric flat-irons and kettles, etc., and so avoid the cost of separate meters for these. It should be fairly easy to arrange an equitable charge, and such consuming devices, if used extensively, will materially improve the load factor of very small stations.

Free Wiring.—The majority of the houses in most of these small districts are tenanted by the poorer classes, and these people cannot incur much expense to adopt electric light. The question of free wiring must therefore be considered. It should be possible for most undertakings to carry out all necessary installation work, up to and including switches and ceiling roses, at a cost with wood-casing work of from 8s. to 10s. per point, the consumer in each case to supply the necessary fittings and lamps, and to purchase these from the undertakers in cash payment.

The wires and fixtures in each free-wired house remain the property of the undertakers, and the tenant is charged, extra to the contract charge for current, a certain fixed sum per quarter or per month, as the case may be, which will offer a fair return on the outlay involved.

A standard form of agreement for these contract consumers can be very carefully drawn up to specify all conditions necessary for the safeguarding of the interests of the undertakers, not the least of which conditions is one specifying that all payments must be made quarterly (or monthly), *in advance.*

The principles which should govern the carrying out of a supply scheme for the very small districts under consideration may therefore be summed up as follows :—

1. Initial capital expenditure to be kept within smallest possible limits.
2. Station buildings to be of simple design and economically constructed, the site to be central in the area of supply.
3. Prime mover up to 100 B.H.P. to be gas engines worked by suction gas, operating in conjunction with a battery of suitable capacity.
4. Size of initial plant installed to be based on the estimated probable maximum demand during the first two years only.
5. Supply pressure 220 volts direct current.

6. Distribution, 2-wire overhead uninsulated mains in all places where permission can be obtained.
7. Contract supply of current for lighting. Meters to be avoided wherever circumstances permit.
8. Free wiring of small consumers' premises, cost of which to be covered by nominal rent, or other approved charge.

There is usually very little prospect, with the majority of these small areas, of a demand for power, heating, or cooking purposes being developed to any appreciable extent; at any rate, not during the earlier years of the undertaking. It may be possible to introduce small domestic utensils such as electric flat-irons, kettles, saucepans, fans, etc., and these, if used extensively, would form a very satisfactory long-hour load.

Case 2.—Small Towns of Population 5,000–15,000.

Much of what has already been stated in regard to the very small districts will apply equally to the considerations of these larger areas, more especially as regards a necessary knowledge of local conditions, the location of the station buildings, the generating plant, and the use of accumulators.

In some of the towns now being considered, there will probably be a number of local industries among which it may be quite possible to develop a fairly large power load, as soon as the electricity supply undertaking has been properly established. Results of past experience, however, go to show that in many places the demand for power during the earlier years of supply is comparatively very small, and the author is therefore of the opinion that the capacity of the initial plant installed should be based almost entirely upon the estimated probable maximum demand, for lighting purposes only, during the first two years. If the power load develops more quickly than was anticipated, it will be a simple matter to install suitable extra plant accordingly. The important point to remember, with all small undertakings, is that the initial capital expenditure shall be kept as small as possible, consistent with an efficient and reliable supply.

The question as to which form of prime mover will be the most economical to adopt in any particular case, in regard to running costs, will be governed by the cost of fuel per ton delivered at the generating station and also by the conditions under which the plant will operate.

Diesel oil engines have a decided advantage over engines working on suction gas, in that they can be started up from rest and put on full load within the short period of less than 2 minutes (the author has actually seen a 100-k.w. Diesel set started up and put on full load in 28 seconds); these engines are also capable of taking an overload of 10 per cent. for 2 hours. A further important point with Diesel plants is that they are very economical when working at light loads. For outputs of less than 100 B.H.P., the balance at present appears to be in favour of suction gas plants on the score of first cost; but

when the initial cost of Diesel plants can be materially reduced, then undoubtedly the demand for these for small supply stations will be very great.

The author has made no mention of steam plants as he considers that for such small outputs they cannot compete against the more modern plants just discussed, unless coal for steam plants can be purchased and delivered on site at a figure of 9s. per ton, or thereabouts.*

Supply Pressure and Distribution.—Unless there is very good prospect of a reasonably large power load being developed, there is little advantage to be gained, all things considered, by adopting a 3-wire supply at 440–220 volts. There will undoubtedly be considerable saving in copper in the mains with this system as compared with a 2-wire 220-volt supply, but against this must be set the extra capital cost of station plant for a balancer set, etc., and for double the number of cells of smaller capacity in the battery.

The question of maintenance and repairs, etc., of the respective systems must also be taken into consideration. It is indisputably the fact that the general lay-out of a 3-wire system is much more complicated than a simple 2-wire system. Although few faults will develop during the early years of the supply, yet in due time, as the mains gradually deteriorate, faults will occur. In a 3-wire system these prove more far-reaching in their effects, and more troublesome to locate and repair. With this system it is also necessary, in order to ensure good balancing, to keep careful records filed of all connections, so that it can be ascertained beforehand to which side of any particular 3-wire distributor a new consumer shall be connected.

In some of the larger of these towns, especially holiday resorts, electric traction may be developed which will call for a 400- to 500-volt supply. It seldom happens, however, that an undertaking is so fortunate as to secure a good traction load within a reasonably short time of the commencement of supply, and hence the question of tramways or other form of electric traction will not usually affect the decision concerning the original pressure and system of supply. Special plant and mains can be installed to meet traction demands when the necessity arises.

Further, while it may not prove a difficult matter to obtain permission to erect bare overhead mains at a pressure of 220 volts, it is extremely doubtful whether a bare 3-wire overhead system with 440 volts across the outers will be sanctioned in the majority of cases for these small towns.

Considering the comparison also from the standpoint of the generating station, the plant for a 2-wire system is cheaper, is very much more simple, is more easily controlled, and hence is more reliable in operation.

* For full details of the comparison between steam, gas, and oil engines, see "Economics of Medium-sized Power Stations," A. J. J. Pfeiffer, *Journal of the Institution of Electrical Engineers*, vol. 43, p. 567, 1909.

Then, as regards street lighting; it would appear that the only type of arc lamp which will continue in use is the flame arc lamp. Ordinary open and enclosed arc lamps are now being rapidly displaced by high candle-power metal filament lamps which are run singly across 220-volt mains; flame arc lamps can be run four in series across the same mains. Finally, electric heaters, cookers, and sundry domestic appliances, cannot safely be operated at pressures exceeding 220 volts, owing to the rough usage to which they are generally subjected.

Hence, it follows that the only real necessity for a supply of 400 to 500 volts is for power purposes, and, as already stated, unless this is likely to assume comparatively large proportions, there can be nothing materially gained, taking all these facts into consideration, by adopting the 3-wire system. The matter may be summed up by stating that, if overhead mains can be erected, the most satisfactory system will be a 2-wire direct-current supply at 220 volts; if the mains have to be laid underground, the question must then be governed by the comparison between the respective costs of the two systems under consideration, for any particular case, as estimated from :—

1. Capital expenditure on station buildings and complete generating plant, including battery and all accessories.
2. Capital expenditure on underground mains, including cost of laying the complete distributing system.
3. Repairs and maintenance of buildings and plant.
4. Repairs and maintenance of mains of all classes.
5. Interest on capital and depreciation, as a percentage of the total of (1) and (2).

The many different methods of laying underground cables are too well known to call for any special mention here; it is merely necessary for any particular scheme to determine which method will prove the most efficient as governed by local circumstances.

While on the subject of cables, special reference must be made to the rapid development during recent years of aluminium for electrical purposes. Bare stranded aluminium conductors have been adopted for many years in various places in America for overhead high-tension transmission lines, and apparently have given every satisfaction. Aluminium conductors have not been used to any great extent in Great Britain, and it would therefore seem that engineers in this country are awaiting definite particulars concerning the behaviour of this metal for underground cable work. Owing to the comparatively short time which has elapsed since they were first introduced, it is difficult to frame a definite opinion as to whether insulated aluminium cables for underground work will prove as satisfactory and as permanent as copper cables, over an extended period of at least 25 years.

Supply Tariffs.—The question of tariffs has aroused a great deal of controversy during recent years consequent on the introduction of the metal filament lamp. In any area of supply the method or methods adopted of charging for current will be, *inter alia*, largely controlled by the total cost of production of electricity, the ruling charges for gas, and the rated value of property.

A method of charging which appears to be gaining favour amongst engineers of supply undertakings is known as the assessment tariff. This consists of charging a certain fixed sum per annum based on the net assessed value of premises, plus a charge of 1d. (or thereabouts) per unit for electricity used for all purposes.

This tariff, however, is almost entirely confined to private residences; for business premises some alternative system is necessary. In a paper read before the Institution in 1908,* Messrs. H. W. Handcock and A. H. Dykes advocated a "contract demand" tariff, which appears to meet the case for business premises in a very fair manner. It is not necessary to describe this tariff here, as it is probably well known by all who are specifically interested in the subject of supply tariffs.

The maximum-demand system appears to have lost favour during recent years, because in a great number of cases it has not proved the success which was anticipated for it. This is due to no defect in the system, as it is theoretically as perfect as any tariff yet devised, but because of the difficulty found in applying it in practice. There is a serious drawback with it in that the account of every consumer must be spread over at least two quarters, one in summer and the other in winter, before any charge can be made. Also the average consumer is unable to detect the real merits of this tariff, and finds it too complicated. For these reasons, therefore, the maximum-demand system is scarcely likely to be adopted to any extent by new undertakings. A flat rate scale of a fixed price per unit with discounts according to the consumption registered, and to certain other conditions, has given satisfactory results for many years, and while perhaps it is not as equitable as the tariffs already discussed, it has the merit of being easily understood, and is therefore often preferable for the average consumer in small towns.

Among the poorer classes and with small consumers generally, the contract system of charging, somewhat on the lines already specified for the smaller undertakings, will probably meet with more approval than any system of charging by meter, and undoubtedly it will be more profitable to the undertaking. In some instances, where free wiring of small premises has been carried out, a charge of 1d. per unit, extra to the ordinary flat rate charges for current, is made for the purpose of covering the extra cost so incurred by the undertakers, but this only applies where these small consumers are charged by meter. The custom of installing meters on small premises is one not to be recommended, as invariably the profit on the very moderate revenue

* *Journal of the Institution of Electrical Engineers*, vol. 41, p. 332, 1908.

received in each case does not cover the cost of repairs, maintenance, and attendance. The contract system eliminates all such charges and ensures a larger revenue, on the whole, for the undertaking.

Prepayment meters have been used to a fairly large extent during recent years, but seeing that a mechanically good and reliable meter is as yet an expensive article, it is fairly obvious that the contract system is much to be preferred, as with this the undertakers incur no further expense than the cost of laying the service mains. The average revenue per lamp per annum from a contract supply will probably be quite as much as, if not greater than, that from prepayment meters.

In regard to special rates for power, heating, and cooking, these must of necessity be fixed as low as possible in places where there are good prospects of a demand of current for such purposes being developed. Manufacturers and others who already are using gas or steam engines, will not oust these and incur the expense of installing electric motors (or pay rent on motors that may be offered on hire by the supply authorities), unless they can be thoroughly convinced that, at the price charged for current, they will effect reasonable economies by changing over to electric driving. Great improvements have been made in the construction of electric heating and cooking appliances during recent years, and prices of such are also very much lower. Practical demonstrations at various places have shown that for cooking purposes electricity can now compete on level terms with gas; and although for heating purposes the latter is cheaper as regards the actual cost of energy, yet the many advantages possessed by electric heaters, particularly for domestic uses, usually more than compensate for this extra cost. Hence, considering these facts, one may reasonably assume that in many of these small towns, the demand for supply for heating and cooking purposes will increase much more rapidly during the next few years than it has in the past.

General Remarks.

It might prove of interest to describe the engineering features of a small central station which was erected twenty-one years ago to supply the town of Galway. The station was built on the site of an old flour mill where a water supply was already to hand. The necessary structural alterations were effected and two submerged type Hercules turbines were fixed, each capable, under a normal head of 11 ft., of developing 75 B.H.P. The dynamos were belt-driven from counter-shafting which was originally connected through bevel-wheel gearing to the turbines; owing to the excessive noise created by the gearing, this was replaced in 1907 by a rope drive from each turbine, using six endless cotton ropes of 1⅜ in. diameter, to each drive. As a precautionary measure against failure of water supply during dry seasons, or from breakdowns of the turbines, etc., a 35-B.H.P. Dowson producer gas plant was installed in 1896 as a standby; there has been no

necessity, however, during the past four years to make any use of this plant.

The mains laid originally in the town area were bare thin split copper tubes; these are supported at intervals of every 6 ft., and enclosed in ordinary 6 in. sewer pipes. The supporters are simply 6-holed glazed earthenware insulators; before erection, all the copper tubes and the insulators were coated with pure shellac varnish. The supply pressure was, as now, 120 volts; of the six tubes forming each distributor, two are joined as the positive and the other four are joined as the negative main. Single-eye sewer pipes were laid opposite every building to which it was anticipated that, sooner or later, a supply would be established, and the service mains (insulated) passed through the holes in the cap of each outlet, and were soldered to the respective bare tubes by means of flat copper strip; the whole cap was then filled in with compound.

The author quite recently inspected these tubes along one of the principal streets of the town, and he found that, except here and there where a tube was corroded and required renewing, they were in a remarkably good state of preservation, considering that they had been in the ground for over twenty years. During the winter months of 1907–1908 it became necessary to install three new feeders, and the method of laying these was somewhat a novel one. The author's attention was attracted by the claims made by the makers of a now well-known fibre conduit, and as the experiments he made on pieces of this conduit demonstrated that it was waterproof, fireproof, mechanically strong, and possessed good insulating qualities, he decided to use the conduit for the purpose of carrying bare copper tubes. The latter were ordered in 6-ft. lengths; each tube is of split, hard-drawn copper, tinned at the ends; the internal and external diameters are respectively $\frac{3}{4}$ in. and $\frac{7}{8}$ in. The fibre conduit was supplied in 5-ft. lengths, each 2 in. internal diameter, with sleeve joints which were made watertight by means of a paste composed of linseed oil and whiting. The copper tubes were joined by driving the ends into one another and running solder through the joints. A special ring insulator of glazed porcelain was fitted to each length before the tubes were jointed; these insulators are an easy fit inside the conduit, and serve the purpose of supporting the copper tubes centrally along and clear of the conduit. These feeders have so far given excellent results; it is impossible, under ordinary circumstances, for a short circuit to develop; and considering the low pressure of the supply, the insulation resistance is ample. Electrolytic corrosion due to surface leakage is reduced to a minimum, as the tubes and the ring insulators, before being put together, were coated with pure shellac varnish. The capacity of each conductor is 200 amperes, at a density of 800 amperes per square inch; the total cost of each feeder, including all material and labour, averaged, roughly, 7s. 6d. per yard of trench. The cost therefore was considerably less than if insulated cables of equal carrying capacity had been installed.

Reverting to the plant, there are now installed four separate batteries, the first of which was erected in 1901 and the last in 1909. These are maintained by the makers under a 10 years' contract, and although the first battery has had continual hard usage for nearly 10 years, it is practically as good as new at present. Each battery comprises 72 cells, and gives a discharge of 165 amperes for 3 hours. The four batteries work in parallel and are operated from the switchboard independently of one another; each battery is regulated by means of 10 end cells.

During the spring of 1909, the author erected a special overhead main to supply a small seaside suburb distant about 1¾ miles from the generating station. Sundry shops and residences along the route of this supply also have been connected. For the first ¾ mile each main is composed of a $\frac{37}{15}$ S.W.G. hard-drawn bare copper strand; the next ½ mile is run with $\frac{19}{16}$ S.W.G. bare strand, and the remainder with $\frac{7}{12}$ S.W.G. bare strand. The cost of the complete new overhead system was £631, and the services cost £127 exclusive of meters. There are at present 65 consumers on this supply, so that the average cost of each service is £1 19s. 1d. Of the number of consumers mentioned, 49 pay by meter (flat rate) and 19 pay under contract. The lighting connections aggregate 1,194 equivalent 30-watt lamps, and the connections for sundry kettles, flat-irons, etc., aggregate 9½ k.w.

The total revenue from all sources (from this extension) during year ending December 31, 1910, was £349 17s. 7d., or £5 7s. 8d. from each consumer. The total cost of repairs and maintenance of the new overhead main including services, for the year 1910, was only £9 3s.

The author has worked out for this particular supply the average revenue per 30-watt lamp connected, over a period of 12 months, with the following results:—

Tariff.	Number of Consumers Considered.	Total Number of Equivalent 30-watt Lamps.	Average Revenue per 30-watt Lamp per Annum.
			s. d.
Flat rate by meter at 5d. per unit	37	673	6 11
Contract rate per lamp, or lump sum	14	368	7 10

These figures are sufficient to show that the average revenue per 30-watt lamp from the contract supply is 13 per cent. higher than that from the flat rate metered supply.

Similar figures taken over the same period of time for various business premises in the town area show a still greater percentage increase in revenue per lamp connected in favour of the contract supply, as will

be seen from the following (under the same headings as the previous list) :—

			s. d.
Flat rate by meter at 5d. per unit	50	2,308	7 4
Contract rate per lamp, or lump sum	53	2,789	10 0

Those interested in the study of the past records of undertakings in towns such as those that form the subject of this paper will find much food for thought in the tables published annually by certain technical journals.* The author has made a special study of these tables, and from them has compiled figures showing the average results of 26 municipal undertakings and 25 private companies in towns having a population of less than 15,000, and where the annual output from the supply station does not exceed 300,000 units. These figures are summarised in the following table :—

Undertaking.	Number of Undertakings.	Capital Expenditure.	Period Working.	Surplus + Deficit −	Working Costs per Unit Sold. (*a*)	Revenue per Unit Sold. (*b*)	Ratio $\frac{a}{b}$.
		£.	Years.	£.	d.	d.	Per Cent.
Municipal	8	25,143	8¼	204 +	2·43	4·79	50·7
	18	26,393	6¾	715 −	2·32	3·61	64·3
Private company	21	29,903	8	347 +	2·35	4·06	57·8
	4	30,630	11½	104 −	2·98	4·42	67·4

Comment on these results is scarcely necessary. One point to be observed in the comparison of columns (*a*) and (*b*) is that the average revenue per unit sold should be not less than twice the working costs per unit sold to insure a reasonable profit on the annual working.

An analysis of these published tables also illustrates the fact that the development or growth of the majority of undertakings in small towns has been very slow ; particularly is this so with municipal undertakings, the average number of consumers per 100 inhabitants with which being 44 per cent. less than the corresponding average connections with the private concerns.

Further, although 84 per cent. of the private companies show a surplus, yet this, after eight years of working, is only, on an average, £347 on a capital expenditure of £29,903, or the net profits represent a mere 1·2 per cent. on the average capital. Such results do not indicate

* *Electrician*, "Tables of Electric Lighting and Power Undertakings," Table I., 1911 ; and *Electrical Times*, "Tables of Costs and Records," 1909–1910. (Central stations without tramway loads.)

very satisfactory business, and it seems apparent that, even with the more successful of these small undertakings, there is much room for improvement.

Of 51 undertakings in small towns, no less than 40 use a 3-wire system of supply at 460–230 volts (or thereabouts). When these plants were first installed the metal filament lamp was unknown, and, of course, not even anticipated. Consequently many of those undertakings that rely to a great extent upon a lighting load only, now have mains installed which are operating at low efficiency as regards the ratio of the present normal load to the full carrying capacity. To improve the efficiency of working, a far greater number of consumers must be connected to the mains than was originally anticipated. A further examination of these tables shows that, with few exceptions, the development of a power load has made very little headway, considering the number of years these undertakings have been in operation.

The author's reasons for reviewing this subject are, first, to demonstrate that, under existing conditions, every small supply undertaking, if properly managed, can be operated with financial success. Secondly, that no direct-current central station is efficiently complete without a battery. Thirdly, that the question of distribution warrants the most careful preliminary investigations, and that a 3-wire system should be adopted only when the area of supply is extensive, and the demand for power is comparatively large, and the lengths of feeders are considerable; otherwise, in the case of the average class of small residential towns, the 2-wire system, even if it is more costly to lay down, is to be preferred, owing to its simplicity of working, and hence greater immunity from breakdown.

Discussion.

Mr. Sowter.

Mr. W. J. U. Sowter: I have had some experience of a small 50-B.H.P. Diesel set, and have found it extremely satisfactory. The set runs usually some 12 hours a day continuously, and there has never been trouble during these working hours. I have heard of continual troubles occurring with small suction-gas plants, and, on the whole, I should give decided preference to Diesel engines. I am not in favour of batteries for small stations, as the upkeep of a battery and its attendance are against it. I have heard a good deal recently of the Wolf locomobile engine, and understand that the makers claim that the fuel consumption of this engine is as low as 0·2 lb. of coal per B.H.P. per hour. If this figure can be substantiated in practice I think we shall hear more of this form of prime mover in the near future. As to the capital costs of suction-gas plants and Diesel engines, I had occasion recently to draw up a scheme for a factory for which 550 k.w. of plant was required. I found that the respective capital costs were £45 per kilowatt for suction gas and £38 per kilowatt for Diesel engines. I quite agree with the author as to a contract tariff for small consumers. I also think that supply authorities should have full powers to under-

take wiring of consumer's installations, etc. I should like to hear from the author whether the figures in the fifth column of the table on page 249 are the financial results after paying interest and sinking fund charges, because if they are, then I think that for municipal undertakings the results are fairly satisfactory. Mr. Sowter

Mr. A. E. PORTE: In regard to item 1 on page 238, I agree as to plant, but I fail to see where any saving in capital expenditure on mains is to be made, because to obtain the necessary number of extra consumers to keep up the revenue in spite of the effect of the metal lamp, the mains must be extended in every direction over a larger area. I have compiled figures from some of the estimates of small stations I have designed, and I find that with suction-gas plants the total capital outlay is less than for Diesel plants, but the difference is not very great, and certainly not worth considering when the running costs of the respective plants are known. I find that with oil at 55s. per ton and coal at 30s. per ton there is a considerable saving in working costs in favour of Diesel plants. Further, if we consider the facility with which oil fuel is stored as compared with the storage of coal, and the cleaner and healthier surroundings of Diesel plants, we at once give the verdict in favour of the latter. I consider the author's figures for annual maintenance of a battery for a small station are too low; I think it would be impossible to obtain such a contract. A more practical figure is 10 per cent. per annum, and at this figure it certainly does not pay to enter into a maintenance contract. I am greatly in favour of batteries myself, and think that no small station should be without one. A battery, in my opinion, should not cost a penny for maintenance during the first five years, and should last, all told, at least fifteen years, with proper supervision. As to the small consumer at 6d. per unit, we can easily compete with gas down to 1s. 6d. per 1,000 cub. ft., but it is quite another matter to compete with paraffin oil. The best we can do with electricity at the price mentioned is to supply 135 c.p.-hours for 1d. With paraffin oil I calculate that with oil at current prices we can get 200 c.p.-hours for 1d. from ordinary paraffin lamps. I think, therefore, it will not prove an easy matter to get small consumers to use electric light instead of paraffin lamps. As regards tariffs, a very good method which I know has been adopted in one or two towns is to charge a fixed annual sum based on the average of the three previous years' accounts, plus a minimum rate based on running costs only, for a supply of electricity for all uses. Mr. Porte.

Mr. G. F. PILDITCH: I think the plant of the future for small undertakings will undoubtedly be either gas or oil engines, as their low running cost is a generally accepted fact. It is impossible to say generally whether batteries should be used or not—each case must be decided individually. Regarding the contract system, the cost of meters is now very low, and, moreover, we can obtain sufficient rental to pay for repairs and capital charges. I should like to know how the author proposes to deal with heating and cooking demands where the contract system is in use; double systems of wiring for the Mr. Pilditch.

Mr. Pilditch. two classes of supply are bad. Free wiring is an absolute necessity in many cases. The hiring charge, however, should be based on the cost of the installation, and not be an extra charge per unit consumed.

Mr. Harriss. Mr. G. M. HARRISS: I think that small stations should adopt a single-phase alternating supply; it is extremely simple, and the plant and mains will be cheaper than a direct-current installation. House wiring with earthed concentric systems is also very cheap. As regards the 3-wire system, I see no difficulties with this, and so far as the balancer is concerned this would not be at all necessary for small towns. The overhead system of distribution presents difficulties in the running of services; overhead wires, if there are many in any one street, become very unsightly. The author gives figures showing that the average revenue per lamp is higher with contracts than it is with metered charges, but he makes no distinction as to the time of day the respective lights are used, and, in my opinion, this factor makes all the difference in the comparison.

Major Davy. Major C. W. DAVY: I have for some time been trying, without success, to find a technical book which deals with the subject of small central supply installations from start to finish. It seems to me a matter of great surprise that there are not more small towns in this country where electricity is in general use, and I should very much like to learn the reason for such want of local enterprise. Nearly every small town in Switzerland and other Continental countries has electric light; the mains are generally run overhead, and even the humblest dwellings use electricity, the installations being put up in a very cheap manner, but efficiently. I must confess that I do not like the contract system of charging, as it seems to be unbusinesslike in principle. I am afraid that overhead systems would not be favoured in many small towns and villages in the British Isles, because the inhabitants pride themselves on the picturesque appearance of their villages, and the general effect may be considerably marred by a number of poles dotted about carrying overhead wires.

Mr. Tatlow. Mr. W. TATLOW: I am afraid that a low-pressure direct-current supply would be comparatively costly for small towns and villages where the streets and houses are very scattered. I see nothing to prevent a 3-wire 440-volt supply from being run overhead in such places, provided the system is installed to comply with the Board of Trade Regulations. A high-tension single-phase supply is probably the best solution as to the system for small scattered areas, with a transformer on each service. I am strongly against the contract system of supply; consumers require a great deal of attention to ensure that they are not wasting current all day. Prepayment meters for small consumers is a far better arrangement than the contract system; gas companies find that slot meters pay very handsomely.

Mr. Price. Mr. S. L. R. PRICE (*communicated*): Although the author is to be congratulated on the way in which he has gathered together a number of very interesting facts and figures in the working out of his subject, I am inclined to think that the question of dealing with small local

demands for electrical energy will all within the comparatively near future be dealt with from centres by large power schemes. Centralisation is the keynote of economy, and the whole question of electric supply must always tend that way. Medium-sized supply undertakings in most cases find it hard enough to make ends meet, but in the smaller cases—except in a few favoured instances—the struggle for existence must necessarily be severe, and, unless owned by one or two private individuals who, being at the same time engineers and business men, are willing to run the business themselves, I do not think there would be much money to be made by the encouragement of very small installations—except perhaps by contractors. Of course, in cases where there is a plentiful supply of water-power the thing may be pushed, but these are very insular cases in this country. Mr. Price.

Mr. P. A. SPALDING (*in reply*): I shall reply to the point raised by Major Davy first, because in so doing I shall at the same time express one of the chief reasons for my preparing this paper. Undoubtedly, the great want of enterprise on the part of local authorities or private investors in small towns is due mainly to the poor reputation earned by existing small undertakings. After carefully studying the statistics relating to the latter, I have come to the conclusion that, either these schemes were designed originally without due regard to local requirements—that the plant and mains laid down were unnecessarily large, and consequently the undertakings are now burdened with excessive capital charges, out of all proportion with the revenue received; or, assuming this deduction to be incorrect, then these undertakings have not been managed efficiently. I mean by this latter statement that the commercial side of the undertaking has been neglected. It is only during comparatively recent years that efficient and systematic businesslike methods have been adopted to develop small undertakings. It is now common knowledge that, by properly educating the local public by means of exhibitions, show-rooms, lectures, and demonstrations of a practical nature, and also by efficient canvassing, the sphere of operations of all undertakings adopting such methods has been increased considerably; consequently, financial results are improved accordingly. A well-managed publicity department should be a permanent part of the organisation of every undertaking in towns of a population of 5,000 and over. I am firmly of the opinion that a battery would be advantageous in every way to all small direct-current undertakings. In fact, within limits, the smaller the station the more urgent is the need of a battery; because in the case of the very small station, if a battery is installed, standby generating plant becomes unnecessary until such time as the demand for the supply exceeds the capabilities of the first generating unit laid down. It follows, therefore, that as a battery is considerably cheaper than the cost of standby plant, a reduction in capital expenditure is effected. I am able to quote figures of a case where a battery was installed in conjunction with a generating plant of 250-k.w. capacity of Diesel oil engines. After the battery had been in use twelve months the station records Mr. Spalding.

Mr. Spalding.

showed that the oil fuel consumption during the year, per unit sold, had decreased 12 per cent., and the annual load factor had increased 10 per cent. As regards small consumers, it does not pay to install meters on these premises, however cheap the meters may be; because, in the first place, these consumers will not pay meter rent, and secondly for this reason, it follows that the development of the smaller consumer class is retarded. It has been proved conclusively at Harrogate, Eccles, and elsewhere that the contract system pays very well, and if this desirable result can be obtained without the cost and trouble of meters, why bother about them at all? Mr. Pilditch apparently has misread the statement as to a contract supply, for other uses than lighting, on small premises. I made no mention of heating and cooking, because candidly I think there is little prospect at present of this class of consumer adopting electricity for such uses. But the workman who has to get up early would find an electric kettle very useful, and his wife, no doubt, would greatly appreciate an electric iron and a small milk heater. It is such utensils that should be supplied at a contract rate; no special wiring becomes necessary, as they can be supplied from any convenient lampholder. This class of consumer would never use such utensils unless the exact cost of so doing is known beforehand. The supply authorities should go a step further and arrange to hire out these utensils at as nominal a figure as possible. It stands to reason that if a workman is asked to pay 12s. down for an electric kettle, or an iron, he will naturally look upon them as a luxury quite beyond his means. On the other hand, he might easily afford to pay, say, 3d. a week for the hire of such utensils. In discussing the question of the comparison between suction gas plants and Diesel oil engines, Mr. Sowter compares figures for a 550-k.w. plant. In doing this, he departs altogether from the limits of my paper. I have compared individual units of 50 H.P. (*i.e.*, total plant capacity of 100 B.H.P.), and I still maintain that the suction gas plant is cheaper in first cost and is more economical to operate with such small units, unless crude oil for Diesel plants can be purchased at low rates compared with the cost of coal. With larger units of from 80 to 100 H.P. each, the saving in first cost with suction gas plants is very much less in proportion; and for units above 100-k.w. capacity the Diesel plant is even cheaper in first cost. Hence no hesitation need be felt in adopting the latter for comparatively large units. Floor space for plant and the question of fuel storage in small towns and villages become items of secondary importance compared with the saving in capital expenditure effected by adopting suction gas plant. There will be less capital expenditure on mains with new undertakings for the reason that, comparing present conditions with those that existed, say, five years ago, and, assuming similar areas of supply, the lighting load in reduced practically by one-half, and hence mains of smaller cross-section can now be laid to cover an equal number of connections. The only difference is, that to increase the connections to bring in a corresponding revenue, more services must be run, but this can be effected very cheaply if over-

Mr. Spalding.

head mains are installed. As regards running a 440-volt 3-wire system overhead, even if permission for this can be obtained, and granted that it effects considerable saving in copper over a 220-volt 2-wire overhead system, yet I contend that the former system with all its troubles and complications, should be avoided in all small towns where the load is mainly lighting. I am afraid that those who so freely exploit the 3-wire system overlook the fact of continual complaints from consumers who are affected by bad local balance of the system. Any engineer who wishes to develop a good heating and cooking load in residential areas will experience endless difficulties in trying to connect such apparatus on either side of the neutral to ensure good local balance. This is obvious when we consider that an ordinary radiator is equivalent to about sixty 16-c.p. metal lamps. However perfect the balance of the whole distributing system may be maintained, the local balance at any particular part of the system may be very bad. The only reply I can give to those who adversely criticise a contract supply to small consumers is to recommend them to carefully peruse Messrs. Handcock and Dykes' recent paper* on this question, and Mr. G. Wilkinson's remarks in the discussion thereon, after which it will be a matter of surprise if the opponent's views are not completely changed. Speaking from some years of practical experience I can fully endorse the arguments put forward in the paper mentioned in favour of the contract system. Concerning the unsightly appearance of the services of overhead systems referred to by two of the speakers, this can be remedied either by arranging with consumers to run services into the backs of the houses from a pole suitably fixed and branched off from the main run, or alternatively by running an overhead connection to a corner wall-bracket secured to the end house of a terrace, and then cleat an armoured service cable along the fronts of the houses under the eave-shoots. I have not experienced much difficulty in obtaining permission to install each arrangement. Mr. Porte raised the question of competition with paraffin lamps. Now the class of consumer who uses such lamps is too ignorant of technicalities to understand such terms as candle-power-hours. What really makes the difficulty of getting electric light substituted is that the prospective customer is too poor to go to the expense of the electric installation. This opens up at once the question of free wiring. I am convinced that if all local authorities had powers to carry out free or assisted wiring in the area of supply, a large number of paraffin lamp users would be converted, and adopt electricity as being unquestionably a cheaper light. If local authorities were vested with these powers, there need be no friction occasioned thereby with local contractors in the larger of the small towns under consideration. The wiring of small installations under free or assisted wiring schemes could be carried out by local contractors by special arrangement. The local contractor then becomes a valuable asset, because he has an interest in common with the local authority in canvassing for consumers, and the undertaking thereby develops to

* *Journal of the Institution of Electrical Engineers*, vol. 44, p. 57, 1910.

Mr. Spalding.

the mutual satisfaction of both parties. Mr. Price apparently is of opinion that small areas should be supplied in bulk from large power stations. I do not agree. Even assuming that these small areas are within a radius of, say, 10 miles of the large power stations, I fail to see what economy the local authority in each case effects by taking a supply in bulk, unless this can be purchased at not more than 1½d. per unit. By taking a bulk supply a local authority thereby eliminates the necessity of a local generating station and plant, but that is all. The distributing system, usually more than one-half the total capital expenditure of the undertaking, remains the same, and a managing engineer and staff also remain a necessity. The local authority save the actual generating costs and the proportion of standing charges on the station building and plant. With modern plant and a properly designed generating station, these two items should not exceed 1¼d. per unit sold for an average small town of a population of about 10,000. If statistics of towns which are supplied in bulk from a large power station are looked up, it will be noticed that with few exceptions these undertakings show a deficit balance on the financial working. Mr. Price's remarks would apply very well, no doubt, to conditions which existed five years ago.

THE MUTUAL ATTRACTIONS OR REPULSIONS OF TWO ELECTRIFIED SPHERICAL CONDUCTORS.

By ALEXANDER RUSSELL, M.A., D.Sc., Member.

(*Paper received September* 21, 1911, *and received in final form December* 28, 1911.)

CONTENTS.

1. *Introduction.*—With the high voltages now employed by electricians for testing the electric strengths of insulating materials, the attracting forces between the electrodes are appreciable, and can be readily measured in absolute units. All that is necessary is an ordinary balance reading to milligrams and a knowledge of the value of the acceleration g produced by the earth's gravity. When the electrodes are spherical and of equal size the attraction between them can in certain cases be computed in terms of the potential difference V between them and the ratio of the distance between them to the radius of either. Equating the computed value to the measured value of the attraction, we find at once the value of V in true volts without making any electrical measurements. This method can be usefully employed for calibrating high-tension voltmeters.

To extend the usefulness of the method the author has recently devised simple approximate formulæ for the attractive forces, etc., between equal spherical conductors. These formulæ have been found so useful in the testing-room that a classified list of them may prove of interest to engineers.

2. *Historical Note.*—Sir W. Snow Harris* was the first to make accurate measurements of the attraction between two electrified

* *Philosophical Transactions of the Royal Society*, 1834, p. 241.

spheres. When the radius of each was one inch he obtained the following results:—

Distance between centres in inches.	2·3	2·5	2·8	3·0
Force in grains weight	15·0	8·25	4·6	3·5

the voltage being the same in each case. Now from known formulæ or from Kelvin's tables* it is easy to compute the voltage in all of the four experiments. If we find the voltage from the first experiment, we may use this value at the other distances to calculate the forces, and comparing the results with Harris's, we can gauge the accuracy of his experiments. William Thomson † (Lord Kelvin) did this in 1845. Unfortunately, however, he makes the assumption that the potential of one of the spheres in Harris's experiments is zero. Judging from the type of apparatus used, it seems to me more probable that the potentials were equal and opposite when the attractions were being weighed. Making this assumption, and assuming that $g = 981 \cdot 2$, we find from the first experiment that—

$$V^2 \times 0 \cdot 3462 = 15 \times 0 \cdot 0648 \times 981 \cdot 2,$$

where V is the potential difference between the spheres.

Hence—

$$V = 52 \cdot 48 \text{ electrostatic units}$$
$$= 15{,}740 \text{ volts.}$$

Assuming this value for V, the author has computed the value in grains weight of the attraction at the other distances. In the following table Harris's observed values, the author's computed values, and Kelvin's computed values, are given:—

c in Inches.	Harris's Observed Values.	Author's Computed Values.	Kelvin's Computed Values.
2·50	8·25	8·25	7·94
2·80	4·60	4·60	4·18
3·00	3·50	3·45	3·00

where c is the distance between the centres of the spheres. It will be seen that Harris's measurements are in almost exact agreement with the values computed by the author.

* Thomson, "Reprint of Papers on Electrostatics and Magnetism," p. 96.
† "Reprint of Papers on Electrostatics and Magnetism," p. 15 *et seq.*

Kelvin* attributed the discrepancy between his calculated values and Harris's measurements to the neglect of the precautions that have to be taken "to avoid the disturbing influence of extraneous conductors." These effects, however, could hardly have produced an error as great as 14 per cent. in his last measurement. The more probable explanation is that the potentials of the spheres were equal and of opposite sign. Accepting this, the calculations prove the extreme accuracy of Harris's measurements. His experiments, however, instead of throwing doubt † on "the views of electricity entertained by the French mathematicians," are a convincing proof of their substantial accuracy.

The author was also surprised to find that the simple approximate theoretical formula which he gives below for the attraction between two equal spheres which are at equal and opposite potentials had been found experimentally by Harris ‡ in 1834.

3. *The Capacity Coefficients and their Rates of Variation.*—Let us consider the case of two spherical conductors each of radius a, and let c be the distance between their centres. If the charges and potentials of the spheres be q_1, q_2, and v_1, v_2 respectively, we have—

$$q_1 = k_{1,1} v_1 + k_{1,2} v_2, \quad \text{and} \quad q_2 = k_{1,1} v_2 + k_{1,2} v_1 \quad . \quad . \quad . \quad (1)$$

where $k_{1,1}$, $k_{1,2}$ are the capacity coefficients of the two spheres.

It is well known § that—

$$k_{1,1} = \lambda \sum_{s=0}^{s=\infty} \frac{1}{\sinh (2s+1)\alpha} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and—

$$-k_{1,2} = \lambda \sum_{s=1}^{s=\infty} \frac{1}{\sinh 2s\alpha} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where $\sinh \alpha = \lambda/a$, and $4\lambda^2 = c^2 - 4a^2$.

If we denote c/a by y, we readily find that—

$$k_{1,1}/a = 1 + \frac{1}{y^2} + \frac{2}{y^4} + \frac{5}{y^6} + \frac{15}{y^8} + \frac{49}{y^{10}} + \frac{166}{y^{12}} + \ldots$$

$$= 1 + \frac{1}{y^2} + \frac{2y^2+1}{(y^3+y)^2 - (2y^2+1)^2} - \frac{1}{y^8} \quad . \quad . \quad . \quad . \quad \| \ (4)$$

approximately.

* "Reprint of Papers on Electrostatics and Magnetism," p. 21.
† W. Snow Harris, "Rudimentary Electricity," p. 105, 1848.
‡ *Cf.* "Reprint of Papers on Electrostatics and Magnetism," p. 20.
§ *Cf.* Maxwell, "Electricity and Magnetism," vol. i., § 173, p. 251, 1881.
|| *Cf. Proceedings of the Physical Society*, vol. 23, p. 358, 1911.

Similarly we find that—

$$-k_{1,2}/a = \frac{1}{y} + \frac{y^3+y}{(y^3+y)^2-(2y^2+1)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad ^{*}(5)$$

$$-\frac{\partial k_{1,1}}{\partial c} = A = \frac{2}{y^3-4y} - \frac{2}{y(y^3-2y)^2} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and—

$$\frac{\partial k_{1,2}}{\partial c} = B = \frac{1}{y^2-4} - \frac{y^2+1}{y^6} - \frac{1}{y^8-4y^6} \quad . \quad . \quad . \quad (7)$$

Even when the distance between the spheres is no greater than their radius the above formulæ may be used with a maximum inaccuracy of about the hundredth part of 1 per cent. For example, when the distance between the spheres is a, $y=3$, and we get from the above formulæ and from Kelvin's tables † the following values :—

	$k_{1,1}/a$.	$-k_{1,2}/a$.	A.	B.
Formulæ	1·14621	0·38899	0·09300	0·06591
Tables	1·14629	0·38908	0·09299	0·06592

For values of c/a less than 3 and greater than 2·1 we may use Kelvin's tables and the tables computed by the author.‡ The values of the variables when c/a lies between 2·1 and 2 can be found either from the tables or from simple formulæ.

5. *The Capacities of the Conductors.*—Maxwell defines the capacity of a conductor as the ratio of its charge to its potential when all neighbouring conductors are at zero potential. According to this definition, therefore, it equals $k_{1,1}$. When the charges on the two spheres are $+q$ and $-q$ respectively, and V is the potential difference between them, then q/V is the capacity K between the spheres, and this is the capacity generally considered by electrical engineers. In this case, if v and $-v$ be the potentials of each sphere—

$$q/2v = K = (k_{1,1} - k_{1,2})/2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

It will also be found convenient in practice to define the component capacity K′ of a conductor when it and all neighbouring conductors are at potential v as q/v, where q is the charge on the conductor. From (1) we have—

$$q/v = K' = k_{1,1} + k_{1,2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

* *Cf. Proceedings of the Physical Society*, vol. 23, p. 358, 1911.
† "Reprint of Papers on Electrostatics and Magnetism," p. 96.
‡ *Proceedings of the Royal Society*, A. vol. 82, p. 530, 1909.

When y is not less than 3 the values of K and K′ can be computed by the formulæ—

$$2\,K/a = \frac{y(y-1)^2}{y(y-1)^2-1} + \frac{y+1}{y^2} - \frac{1}{y^8} \quad . \quad . \quad . \quad . \quad (10)$$

and—

$$K'/a = \frac{y(y+1)^2}{y(y+1)^2+1} - \frac{y-1}{y^2} - \frac{1}{y^8} \quad . \quad . \quad . \quad . \quad (11)$$

For example, we find that when y is 3 :—

	K.	K′.
Formulæ (10) and (11)	0·76760	0·75722
Kelvin's tables	0·76765	0·75721

When c/a, *i.e.*, y, is greater than 8, the very simple formulæ—

$$\frac{2\,K}{a} = 1 + \frac{1}{y} + \frac{1}{y^2} + \frac{1}{y^3} + \frac{2}{y^4} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

and—

$$\frac{K'}{a} = 1 - \frac{1}{y} + \frac{1}{y^2} - \frac{1}{y^3} + \frac{2}{y^4} \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

may be used, the maximum inaccuracy being less than the hundredth part of 1 per cent.

With the same accuracy also the following formulæ may be used when c/a is not greater than 2·1 :—

$$K = \frac{a}{6}\left(1 + \frac{c}{4\,a}\right)\left(2{\cdot}3186 + \log\frac{a}{c-2\,a} + \frac{c}{9\,a}\right) \quad . \quad . \quad . \quad (14)$$

and—

$$K' = a\left(1 + \frac{c}{4\,a}\right)\left(0{\cdot}5177 - \frac{c}{36\,a}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

When c/a is as great as 2·5 the error due to using either of these formulæ is only about the tenth part of 1 per cent. Even when c/a is as great as 3·6 the error due to using (15) is less than 1 per cent.

We see that when the distance between the spheres is infinitely small, K is infinite and K′ equals 0·6931 a. As the distance between the spheres increases K continually diminishes and K′ continually increases. Finally, when the distance between them is infinite, K equals $a/2$ and K′ equals a.

5. *The Charging Current.*—When two equal spherical electrodes are connected by thin wires with the terminals of a transformer or an induction coil, we see at once from (1) that—

$$\left.\begin{aligned} i_1 &= k_{1,1}\frac{\partial v_1}{\partial t} + k_{1,2}\frac{\partial v_2}{\partial t} \\ \text{and—}\qquad & \\ i_2 &= k_{1,1}\frac{\partial v_2}{\partial t} + k_{1,2}\frac{\partial v_1}{\partial t} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

where i_1 and i_2 are the instantaneous values of the currents in the leads to the electrodes.

The two practical cases are when the middle point of the secondary winding is connected with the earth, and when one of the electrodes is connected with the earth. If the potential difference between the electrodes be $E \sin \omega t$, we get, in the first case, that—

TABLE OF THE VALUES OF K AND K′.

$y = \frac{c}{a}$	K/a.	K′/a.	$y = \frac{c}{a}$	K/a.	K′/a.
$2{\cdot}0_61$	4·6647	0·6931	2·6	0·8552	0·7340
$2{\cdot}0_51$	4·0891	0·6931	2·7	0·8275	0·7401
$2{\cdot}0_41$	3·5134	0·6931	2·8	0·8044	0·7460
$2{\cdot}0_31$	2·9378	0·6931	2·9	0·7847	0·7517
$2{\cdot}0_21$	2·3626	0·6932	3·0	0·7677	0·7572
2·01	1·7896	0·6942	3·1	0·7528	0·7625
2·02	1·6191	0·6946	3·2	0·7396	0·7677
2·03	1·5202	0·6954	3·3	0·7278	0·7726
2·04	1·4506	0·6961	3·4	0·7172	0·7774
2·05	1·3970	0·6968	3·5	0·7076	0·7820
2·06	1·3536	0·6975	3·6	0·6989	0·7864
2·07	1·3171	0·6983	3·7	0·6909	0·7907
2·08	1·2857	0·6990	3·8	0·6836	0·7948
2·09	1·2582	0·6997	3·9	0·6768	0·7988
2·10	1·2337	0·7004	4	0·6705	0·8026
2·15	1·1413	0·7040	5	0·6263	0·8345
2·20	1·0775	0·7075	6	0·6006	0·8577
2·25	1·0291	0·7117	7	0·5836	0·8753
2·30	0·9911	0·7144	8	0·5712	0·8891
2·35	0·9594	0·7178	9	0·5626	0·9001
2·40	0·9326	0·7211	10	0·5556	0·9092
2·45	0·9095	0·7245	100	0·5051	0·9901
2·50	0·8892	0·7277	1,000	0·5005	0·9990

$$i_1 = i_2 = \omega \, K \, E \cos \omega t$$

and therefore—

$$A_1 = A_2 = \omega \, K V \times 10^{-6} \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

where A_1, A_2 are the effective values of the currents in the leads in amperes, ω is 2π times the frequency, K is the capacity in microfarads, and V is the effective pressure in volts. Similarly we find that in the second case—

and—

$$\left.\begin{aligned} A_1 &= \omega \, k_{1,1} V \times 10^{-6} \\ A_2 &= -\omega \, k_{1,2} V \times 10^{-6} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

For example, let us suppose that the frequency of the alternating current is 50 and that the secondary pressure is 100 kilovolts. If the

radius of each electrode be 10 cm., and the distance between them be also 10 cm., we find by (4), (5), and (10) that—

$$k_{1,1} = 1{\cdot}146 \times 10/900{,}000 \text{ microfarads}$$
$$-k_{1,2} = 0{\cdot}389 \times 10/900{,}000 \quad ,,$$

and—

$$K = 0{\cdot}768 \times 10/900{,}000 \quad ,,$$

Hence when the middle point of the secondary winding is earthed—

$$A_1 = A_2 = 0{\cdot}000268 \text{ ampere.}$$

And when the second electrode is earthed—

$$A_1 = 0{\cdot}000400 \text{ ampere,}$$

and—

$$A_2 = 0{\cdot}000136 \quad ,,$$

6. *The Laws of Attraction and Repulsion between the Spheres when the Potentials are given.*—When the potentials of the spheres are maintained constant, and they alter their positions owing to their mutual electric actions, they move in such a way that the electrostatic energy of the system is increased by an amount exactly equal to the work done on the spheres by the electric forces. If W be the electrostatic energy—

$$W = \tfrac{1}{2} k_{1,1} (v_1^2 + v_2^2) + k_{1,2} v_1 v_2$$

and hence—

$$F = \frac{\partial W}{\partial c} = -\frac{1}{2} A (v_1^2 + v_2^2) + B v_1 v_2 \quad . \quad . \quad . \quad . \quad (19)$$

If F is negative W increases as c diminishes, and therefore the force is attractive. When F is positive the force is repulsive. If v_1 and v_2 are of opposite sign the force is always attractive, but when they are of the same sign the force can be attractive, zero, or repulsive, according to their distance apart. If v_1 be the smaller potential, then the force is zero when—

$$\frac{v_1}{v_2} = \frac{B}{A} - \left(\frac{B^2}{A^2} - 1\right)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

The values of v_1/v_2 for zero force have been tabulated by Kelvin from $y = 2{\cdot}1$ to $y = 4$. The value when y is outside these limits can be readily found from the formulæ in this paper.

In practice the three most important cases are (1) when the potentials are equal and opposite, (2) when they are equal, and (3) when one of them is zero.

In the first case the force F is attractive, and is given by—

$$F = (B + A) v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

when v and $-v$ are the potentials of the spheres. In the second case it is repulsive, and is given by—

$$F' = (B - A) v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

where the potential of each sphere is v. In the third case we get—

$$F'' = \tfrac{1}{2} A v_1^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

the force being always attractive.

From (6) and (7) we get—

$$F = \left(\frac{1}{y^2 - 2y} - \frac{1}{y^4} - \frac{(1+y)^2}{y^8} - 4\frac{2y^2 + y + 6}{y^{11}}\right) v^2 \quad . \quad . \quad (24)$$

$$F' = \left(\frac{1}{y^2 + 2y} - \frac{1}{y^4} - \frac{(1-y)^2}{y^8} + 4\frac{2y^2 - y + 6}{y^{11}}\right) v^2 \quad . \quad . \quad (25)$$

and—

$$F'' = \left(\frac{1}{y^3 - 4y} - \frac{1}{y(y^3 - 2y)^2}\right) v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

When y is large we get—

$$F = \frac{v^2}{y^2 - 2y} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

the denominator of which is the same as in Harris's formula. In this case also F'' varies inversely as y^3, and therefore inversely * as c^3.

When y is less than 2·001 the author has shown that we have, very approximately—

$$F = \frac{a v^2}{2(c - 2a)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28)$$

and—

$$F' = 0{\cdot}07386\, v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

where the potentials of the spheres are v and $-v$ respectively in the first case, and are each v in the second case.

Writing $F = \alpha \dfrac{a^2}{c^2} v^2$ and $F' = \alpha' \dfrac{a^2}{c^2} v^2$, the table on page 265 shows how the values of α and α' vary with the distance between the spheres.

We see that for values of c/a greater than 10, the formulæ—

$$F = \frac{a^2}{c^2} \frac{1}{1 - 2a/c} v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

and—

$$F' = \frac{a^2}{c^2} \frac{1}{1 + 2a/c} v^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

give a four-figure accuracy.

* *Cf.* Thomson, "Reprint of Papers on Electrostatics and Magnetism," pp. 20, 21.

If S be the surface ($2\pi a^2$) of each of the opposing hemispheres, and the distance between them is sufficiently great, we have—

$$F = \frac{a^2 v^2}{c^2} = \frac{S(2v)^2}{8\pi c^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (32)$$

the same formula as for the attraction between two parallel plates each of area S at a very small distance c apart, and the difference of potential between which is $2v$.

$\frac{c}{a}$	α.	α'.	$\frac{c}{a}$	α.	α'
$2{\cdot}0_6 1$	20×10^6	0·295	7	1·379	0·757
$2{\cdot}0_5 1$	20×10^5	0·295	8	1·318	0·784
$2{\cdot}0_4 1$	20×10^4	0·295	9	1·273	0·805
$2{\cdot}0_3 1$	20×10^3	0·295	10	1·240	0·824
$2{\cdot}0_2 1$	20×10^2	0·296	20	1·111	0·909
2·01	$19{\cdot}9 \times 10$	0·298	30	1·071	0·937
2·1	20·399	0·317	40	1·053	0·952
3·0	2·860	0·487	50	1·042	0·962
4·0	1·931	0·603	100	1·020	0·980
5·0	1·624	0·673	1,000	1·002	0·998
6·0	1·472	0·722	10,000	1·000	1·000

7. *The Laws of Attraction and Repulsion between the Spheres when the Charges are given.*—When the charges have values q_1 and q_2 we readily find from (1) and (19) that—

$$F = C q_1 q_2 - \tfrac{1}{2} D (q_1^2 + q_2^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (33)$$

where—

$$C = [B(k_{1,1}^2 + k_{1,2}^2) + 2A k_{1,1} k_{1,2}]/(k_{1,1}^2 - k_{1,2}^2)^2$$

and—

$$D = [A(k_{1,1}^2 + k_{1,2}^2) + 2B k_{1,1} k_{1,2}]/(k_{1,1}^2 - k_{1,2}^2)^2.$$

When F is negative the force is attractive, and when it is positive the force is repulsive. When q_1 and q_2 are of opposite signs the force is always attractive. But when they are of the same sign it may be

attractive, zero, or repulsive. If q_1 be the smaller charge, F′ vanishes when—

$$\frac{q_1}{q_2} = \frac{C}{D} - \left(\frac{C^2}{D^2} - 1\right)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (34)$$

When $q_1 = - q_2 = q$, formula (33) gives for the attraction F—

$$F = q^2 \frac{B + A}{(k_{1,1} - k_{1,2})^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

and when $q_1 = q_2 = q$ the repulsion F′ is given by—

$$F' = q^2 \frac{B - A}{(k_{1,1} + k_{1,2})^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (36)$$

The formulæ may be written—

$$F = \beta \frac{q^2}{c^2} \quad \text{and} \quad F' = \beta' \frac{q^2}{c^2}.$$

When y is greater than 3, β and β' can be computed by the formulæ—

$$\beta = 1 + \frac{4}{y^3} + 2\frac{(y+1)(3y+4)}{y^7} + \frac{54}{y^8} + \frac{50}{y^6(y-1)^3} \quad . \quad . \quad (37)$$

and—

$$\beta' = 1 - \frac{4}{y^3} - 2\frac{(y-1)(3y-4)}{y^7} + \frac{54}{y^8} - \frac{50}{y^6(y+1)^3} \quad . \quad . \quad (38)$$

For example, when y is 3, we get $\beta = 1{\cdot}2129$, and $\beta' = 0{\cdot}8498$ by the formulæ. From Kelvin's tables we find their values given as 1·2134 and 0·8498 respectively.

The following table shows how β and β' vary as c increases :—

$\frac{c}{a}$	β.	β'.	$\frac{c}{a}$	β.	β'.
2·0	∞	0·615	2·01	$1{\cdot}56 \times 10$	0·618
$2{\cdot}0_6 1$	$5{\cdot}77 \times 10^5$	0·615	2·10	3·355	0·643
$2{\cdot}0_5 1$	$2{\cdot}99 \times 10^4$	0·615	3·00	1·213	0·850
$2{\cdot}0_4 1$	$4{\cdot}05 \times 10^3$	0·615	4·00	1·074	0·935
$2{\cdot}0_3 1$	$5{\cdot}79 \times 10^2$	0·615	10·00	1·004	0·996
$2{\cdot}0_2 1$	$9{\cdot}11 \times 10$	0·615	20·00	1·001	1·000

It will be seen that β and β' approach their asymptotic value of unity much more rapidly than α and α' do.

In using the above formulæ it has to be remembered that the electrostatic units of pressure, quantity, and capacity equal 300, $1/(3 \times 10^9)$ and $1/(9 \times 10^{11})$ times the volt, the coulomb, and the farad respectively.

To illustrate these formulæ let us consider the case of two conducting spheres, each of radius 1 cm. and at a distance apart of 1 cm. We shall find their charges, their potentials, and their capacities (*a*) when they attract one another with a force of 1 dyne, and (*b*) when they repel one another with a force of 1 dyne.

(*a*) *Attraction.*—Let q, $-q$, and v, $-v$ be the charges and potentials of the spheres. From the tables given above we get, when the attractive force equals 1 dyne—

$$1{\cdot}213 \frac{q^2}{9} = 1, \quad \text{and} \quad 2{\cdot}860 \frac{v^2}{9} = 1.$$

Hence—

$$\begin{aligned} q &= 2{\cdot}724 \text{ electrostatic units} \\ &= 0{\cdot}908 \times 10^{-9} \text{ coulombs,} \end{aligned}$$

and—

$$\begin{aligned} v &= 1{\cdot}774 \text{ electrostatic units} \\ &= 532 \text{ volts.} \end{aligned}$$

In this case the capacity K between the spheres is given by—

$$\begin{aligned} K = q/(2\,v) &= 0{\cdot}908 \times 10^{-9}/1{,}064 \text{ farads} \\ &= 0{\cdot}768 \text{ electrostatic units,} \end{aligned}$$

which agrees with the number given in the table above.

(*b*) *Repulsion.*—Let q_1, q_1, and v_1, v_1 be the charges and potentials of the spheres in this case. We have—

$$0{\cdot}850 \frac{q_1^2}{9} = 1, \quad \text{and} \quad 0{\cdot}487 \frac{v_1^2}{9} = 1.$$

Hence—

$$\begin{aligned} q_1 &= 3{\cdot}255 \text{ electrostatic units} \\ &= 1{\cdot}085 \times 10^{-9} \text{ coulombs,} \end{aligned}$$

and—

$$\begin{aligned} v_1 &= 4{\cdot}225 \text{ electrostatic units} \\ &= 1{,}290 \text{ volts.} \end{aligned}$$

Therefore—

$$\begin{aligned} K' = q_1/v_1 &= 1{\cdot}085 \times 10^{-9}/1{,}290 \text{ farads} \\ &= 0{\cdot}757 \text{ electrostatic units.} \end{aligned}$$

It has to be noticed that the electric strength of the dielectric fixes a maximum possible limit to the attractive force between two electrified conductors. In the above case if the air were at 0° C. and 76 cm. pressure a disruptive discharge would take place when the potential difference between the spheres was a little less than 32,000 volts. In this case the attraction between them is only about 0·92 of the weight of a gramme.

8. *Summary.*—In this paper tables and formulæ are given by means of which the capacity between two equal spheres and the component capacity of each of them, whatever their distance apart, can be found at once. Hence the charging currents to spherical electrodes can also be readily found. Very simple formulæ which enable the rates of variation of the capacity coefficients to be accurately computed when the distance between the spheres is not less than the radius of either are given. We can thus, with the help of other formulæ previously given by the author, determine the numerical values of the attractions and repulsions between equal spherical conductors either when their charges or when their potentials are given. Tables are given illustrating the magnitude of the errors introduced into Coulomb's law for the attraction or repulsion of small electrified conductors by the neglect of the magnitude of these conductors. In an historical note it is pointed out that Snow Harris made extremely accurate measurements of the electrostatic attraction between equal spherical conductors in 1834.

REPORT ON FIVE SAMPLES OF MAGNETIC SHEET MATERIAL TESTED FOR TOTAL LOSS AND HYSTERESIS AT THE PHYSIKALISCH - TECHNISCHE REICHSANSTALT, THE BUREAU OF STANDARDS, AND THE NATIONAL PHYSICAL LABORATORY.

By ALBERT CAMPBELL, B.A., Associate Member, H. C. H. BOOTH, and D. W. DYE, B.Sc.

(FROM THE NATIONAL PHYSICAL LABORATORY.)

(*Paper first received June* 20, 1911, *received in final form August* 28, 1911.)

As the methods of testing the magnetic properties of iron with alternating current are becoming more definite and accurate, it appeared desirable to ascertain to what extent the results obtained in various laboratories agreed with one another. To this end the Physikalisch-Technische Reichsanstalt (P.T.R.) and the Bureau of Standards (B.S.) kindly co-operated with us (the N.P.L.) in making tests on sets of iron strips which were in some cases identical with one another and in other cases were cut from immediately adjacent parts of the same sheets. As the actual reports received from the P.T.R. and the B.S. are given in Appendices I. and II., we need not preface the combined tabulation of the results by more than a very brief allusion to the methods used; the details of these have already been published elsewhere (see Appendix III.).

The experiments were made on samples of five different materials (A, B, C, D, and E) in the form of sheet approximately 0·5 mm. thick, samples B and D being silicon-iron alloys. The samples were kindly provided by Messrs. J. Lysaght, to whom we would here express our best thanks.

The P.T.R. tests were made by the Epstein method using strips 50 cm. × 3 cm., four bundles being formed into a square with butt joints; while for the B.S. and the N.P.L. tests the method suggested by Lloyd and Fisher was used, in which strips of 25·4 cm. × 5 cm. were

arranged in a square with good magnetic joints at the corners, formed by angle-pieces interleaved with the ends of the strips and tightly clamped together. The separation of the hysteresis and eddy-current losses was made in the P.T.R. and the B.S. by varying the frequency, while in the N.P.L. it was done by varying the form factor with a constant frequency of 50∿ per second.

As the object was only to compare the methods, all the strips were cut in the direction of the grain of the material. As the size of the strips used at the B.S. and N.P.L. is the same, strips marked 1 were first tested at the N.P.L.; they were then sent to the B.S., and on their return eight months later were again tested (twice over) by the N.P.L. A second series marked 2, adjoining Set 1 in the cutting of the sheets, were also tested in the N.P.L. before the return of series 1. The strips for the P.T.R. were twice the length, and were cut from positions in the sheets immediately adjacent to Sets 1 and 2.

In carrying out the tests of Set 2, it was found that the electrical contact which occurred between the strips and the corner pieces where they overlapped tended to increase the total loss. For example, when the surfaces were very clean, improvement of the contact by increasing the pressure of the clamps caused large increase in the eddy-current loss, while scarcely affecting the hysteresis. Accordingly, to eliminate this source of error, all the samples were retested with very thin paper (0·04 mm. thick) between all the joints; all such tests are marked *p* in what follows. In the B.S. tests the overlap was of the order of 2 mm., while in those of the N.P.L. it was about 5 mm. Thus the effect of the contacts would be considerably accentuated in the latter case. This surface contact effect appeared to give rise to serious errors only in the case of Sample A. The tests at the P.T.R. were all made with $B_{max.} = 10{,}000$, while those at the B.S. and the N.P.L. were made both at $B_{max.} = 10{,}000$ and 5,000.

Reduction of Results.

In the various tests two conditions were not quite uniform; the B.S. results refer to a temperature of 25° C., while all the others refer to 15° C. In the N.P.L. tests the densities of samples A, C, and E were each taken as 7·80, while those of B and D were found by experiment to be 7·62 and 7·60 respectively. The densities used by the other two laboratories were slightly different in some cases; these, as well as all the results in the form originally received, are given in Table I. In order to obtain a more close comparison between the results, for convenience they have all been reduced to 15° C. and to the densities used in the N.P.L. tests. For the temperature reductions, a temperature coefficient of 0·5 per cent. per ° C. was used for A, C, and E, and 0·1 per cent. per ° C. for B and D. For the density reductions the hysteresis and eddy-current losses were taken as proportional to $B^{1.6}_{max.}$ and $B^{2}_{max.}$ respectively, a sufficiently close approximation. The reduced results

Table I.

Unreduced Results (as Received).

Sample.	Temperature.		Density.		Total Loss.		Hysteresis.	
	P.T.R.	B.S.	P.T.R.	B.S.	P.T.R.	B.S.	P.T.R.	B.S.
At $B_{max.}$ = 10,000.								
A	15° C.	25° C.	7·80	7·76	3·37	3·37$_0$	1·90$_5$	1·91$_0$
C	15° C.	25° C.	7·80	7·72	3·41	3·42$_0$	2·03$_5$	2·09$_0$
E	15° C.	25° C.	7·80	7·79	5·01	5·12$_5$	3·51$_5$	3·60$_5$
B	15° C.	25° C.	7·58	7·56	2·04	2·08$_0$	1·64$_5$	1·68$_0$
D	15° C.	25° C.	7·57	7·55	1·95	1·95$_0$	1·51	1·53$_0$
At $B_{max.}$ = 5,000.								
A	—	—	—	—	—	1·03$_0$	—	0·66$_0$
C	—	—	—	—	—	1·04$_5$	—	0·73$_5$
E	—	—	—	—	—	1·66$_5$	—	1·24$_5$
B	—	—	—	—	—	0·65$_0$	—	0·55$_0$
D	—	—	—	—	—	0·61$_0$	—	0·49$_0$

Table II.

Total Loss (reduced Values).

($B_{max.}$ = 10,000.)

Sample.	P.T.R.	B.S.	N.P.L.					
			1.	1 *a*.	1 *p*.	2.	2 *p*.	2 Interleaved.
A ...	3·37	3·41$_3$	3·57	3·44$_5$	3·43$_0$	3·52$_5$	3·36$_0$	—
C ...	3·41	3·42$_4$	3·46$_5$	3·49$_0$	3·48	3·43	3·39$_0$	3·42$_5$
E ...	5·01	5·19$_3$	5·15	5·2$_5$	5·22	5·11	5·05	—
B ...	2·02$_2$	2·05$_7$	2·10	2·06$_5$	2·08$_4$	2·07$_8$	2·06$_5$	2·05
D ...	1·93$_3$	1·93$_3$	1·98	1·95$_0$	1·93$_8$	1·96$_3$	1·95$_4$	—

are given in Tables II., III., IV., and V. In the N.P.L. results the marks have the following meaning:—

1. Original tests on (1).
1 *a*. Tests after return from America.
1 *p*. Tests after return from America with paper in joints.
2. Tests in 1911 on neighbouring samples to (1).
2 *p*. Same as 2, but with paper in joints.

The losses are expressed in watts per kilogram at 50 cycles per second with secondary induced voltage of sine wave-form.

TABLE III.

Hysteresis Loss (reduced Values).

($B_{max.}$ = 10,000.)

Sample.	P.T.R.	B.S.	N.P.L.					
			1.	1 *a*.	1 *p*.	2.	2 *p*.	2 Inter-leaved.
A ...	$1{\cdot}90_5$	$1{\cdot}89_5$	1·98	$1{\cdot}98_0$	$2{\cdot}02_5$	$1{\cdot}95_0$	$1{\cdot}94_5$	—
C ...	$2{\cdot}03_5$	$2{\cdot}05_7$	2·08	$2{\cdot}12_0$	2·15	2·09	$2{\cdot}01_5$	2·02
E ...	$3{\cdot}51_5$	$3{\cdot}59_8$	3·50	3·64	3·69	3·38	3·51	—
B ...	$1{\cdot}63_1$	$1{\cdot}65_9$	1·68	$1{\cdot}65_0$	$1{\cdot}68_3$	$1{\cdot}64_6$	$1{\cdot}65_0$	$1{\cdot}62_7$
D ...	1·50	$1{\cdot}51_4$	1·56	$1{\cdot}56_4$	$1{\cdot}50_5$	$1{\cdot}55_3$	$1{\cdot}55_2$	—

TABLE IV.

Total Loss (reduced Values).

($B_{max.}$ = 5,000.)

Sample.	B.S.	N.P.L.					
		1.	1 *a*.	1 *p*.	2.	2 *p*.	2 Inter-leaved.
A	$1{\cdot}03_9$	$1{\cdot}10_5$	$1{\cdot}04_2$	$1{\cdot}03_5$	$1{\cdot}07_0$	$1{\cdot}02_0$	—
C	$1{\cdot}04_2$	$1{\cdot}04_9$	$1{\cdot}06_4$	$1{\cdot}04_7$	$1{\cdot}03_9$	$1{\cdot}03_8$	$1{\cdot}03_7$
E	$1{\cdot}68_3$	$1{\cdot}66_3$	$1{\cdot}68_5$	$1{\cdot}67_7$	$1{\cdot}66_8$	$1{\cdot}63_5$	—
B	0·643	0·652	0·650	0·645	0·649	0·650	—
D	0·604	0·613	0·611	0·602	0·614	0·609	—

In Tables VI., VII., VIII., and IX. are given the percentage differences from Series 2 *p*; it appeared that this set, not being far from the general mean, was the best with which to compare all the others.

Table V.

Hysteresis Loss (reduced Values).

($B_{max.} = 5{,}000.$)

Sample.	B.S.	N.P.L.					
		1.	1 *a*.	1 *p*.	2.	2 *p*.	2 Inter-leaved.
A	0·655	0·727	0·700	0·710	0·723	0·723	—
C	0·723	0·730	0·767	0·765	0·750	0·750	0·736
E	1·24$_2$	1·23$_5$	1·25$_4$	1·27$_6$	1·24$_5$	1·25$_0$	—
B	0·543	0·553	0·545	0·549	0·544	0·550	—
D	0·485	0·497	0·500	0·496	0·501	0·497	—

Table VI.

Total Loss (reduced Values).

($B_{max.} = 10{,}000.$)

Percentage difference from N.P.L., 2 *p*.

Sample.	P.T.R.	B.S.	N.P.L.					
			1.	1 *a*.	1 *p*.	2.	2 *p*.	2 Inter-leaved.
A	+0·3	+1·6	+6·3	+2·5	+2·1	+4·9	0·0	—
C	+0·6	+1·0	+2·2	+2·9	+2·7	+1·2	0·0	+1·0
E	−0·8	+2·8	+2·0	+4·0	+3·4	+1·2	0·0	—
B	−2·1	−0·4	+1·7	0·0	+0·9	+0·6	0·0	−0·7
D	−1·1	−1·1	+1·3	−0·2	−0·8	+0·6	0·0	—
Mean ...	−0·6	+0·8	+2·7	+1·8	+1·7	+1·7	0·0	—
Mean ... (excluding A)	−0·7	+0·6	+1·8	+1·7	+1·5	+0·9	0·0	—

The numbers in the column marked "2 Interleaved" refer to tests described below (after Remarks on Results).

Remarks on Results.

If it be remembered that the probable limits of error are about ± 1 per cent. for total loss and about ± 2 per cent. for hysteresis loss, the agreement between the various means is quite satisfactory.

Some of the tests on sample A gave abnormal results. This material was of very high conductivity, and the strips when in the unoxidised

Table VII.

Hysteresis Loss (reduced Values).

($B_{max.}$ = 10,000.)

Percentage difference from N.P.L., 2*p*.

Sample.	P.T.R.	B.S.	N.P.L. 1.	N.P.L. 1 *a*.	N.P.L. 1 *p*.	N.P.L. 2.	N.P.L. 2 *p*.	N.P.L. 2 Interleaved.
A	−2·0	−2·6	+1·8	+1·3	+4·1	+0·3	0·0	—
C	+1·0	+2·1	+3·2	+4·8	+6·7	+3·7	0·0	+0·2
E	+0·2	+2·5	−0·3	+3·7	+2·0	−3·7	0·0	—
B	−1·2	+0·5	+1·8	0·0	+2·0	−0·2	0·0	−1·4
D	−3·3	−2·5	+0·5	+0·8	−3·0	−0·1	0·0	—
Mean ...	−1·1	0·0	+1·4	+2·1	+2·4	0·0	0·0	—
Mean ... (excluding A)	−0·7	+0·6	+1·3	+2·3	+1·9	0·0	0·0	—

condition showed, in the N.P.L. tests, considerably lower loss when paper was inserted in the joints. As has been already mentioned, this effect was found to be due to the increase in eddy-current loss due to the good electrical contacts when the clean metal surfaces overlapped at the joints. In A (1 *a*) the strips showed considerable oxidation which had not been present in the original tests A (1) before sending to America. This oxidation no doubt accounts for the fact that A (1 *a*) gave results very similar to the B.S. tests and that the insertion of paper made comparatively little difference. On account of these abnormal values in sample A, a line has been added to the percentage tables giving the means excluding A.

TABLE VIII.

Total Loss (reduced Values).

($B_{max.} = 5{,}000.$)

Percentage difference from N.P.L., 2 *p*.

Sample.	B.S.	N.P.L. 1.	1 *a*.	1 *p*.	2.	2 *p*.	2 Inter-leaved.
A	+1·8	+8·3	+2·2	+1·5	+4·4	0·0	—
C	+0·4	+1·1	+2·5	+0·9	+0·1	0·0	−0·1
E	+2·9	+1·7	+3·0	+2·6	+2·0	0·0	—
B	−1·1	+0·3	0·0	−0·1	−0·1	0·0	—
D	−0·8	+0·7	+0·3	−0·1	+0·8	0·0	—
Mean	+0·6	+2·4	+1·6	+1·0	+1·4	0·0	—
Mean ... ... (excluding A)	+0·1	+0·9	+1·4	+0·8	+0·7	0·0	—

TABLE IX.

Hysteresis Loss (reduced Values).

($B_{max.} = 5{,}000.$)

Percentage difference from N.P.L., 2 *p*.

Sample.	B.S.	N.P.L. 1.	1 *a*.	1 *p*.	2.	2 *p*.	2 Inter-leaved.
A	−9·4	−0·5	−3·1	−1·8	0·0	0·0	—
C	−3·6	−2·7	+2·3	+2·0	0·0	0·0	−1·9
E	−0·6	−1·2	+0·3	+2·0	−0·4	0·0	—
B	−1·3	+0·5	−0·1	−0·2	−1·1	0·0	—
D	−2·4	0·0	+0·1	−0·2	+0·8	0·0	-
Mean	−3·5	−0·8	−0·1	+0·4	−0·1	0·0	—
Mean ... ... (excluding A)	−2·0	−0·7	−0·6	+0·9	−0·2	0·0	—

We may here mention that in 1909 some experiments were made in the N.P.L. to compare the results given by the Lloyd-Fisher square with those given by rings. When the effects of cutting were avoided by using hard-rolled material, the square and the ring gave identical results. This material, of course, showed very high hysteresis loss with relatively small eddy-current loss, and hence is not quite representative of good commercial samples.

Tests with Interleaved Square.

Since the above tests were made, Mr. L. W. Wild * has published the results of some experiments in which the same strips were tested for total loss when assembled in a square (*a*) with corner pieces after Lloyd and Fisher, (*b*) with interleaved (imbricated) corners as used originally by Searle and others. With silicon iron (Stalloy) his results gave discrepancies between the two methods of the order of 10 per cent. In order to test this point we carried out tests on samples C 2 and B 2, interleaving the strips without any corner pieces (but with paper between) in exactly the same manner as case (*b*) above mentioned. The results are given in the last columns of Tables II. to IX., and it will be seen that in no case do they differ by more than 1 per cent. from Set 2 *p* tested with corner-pieces. A similar comparison made with sample C 2 (silicon iron) at $B_{max.} = 15{,}000$ showed practical agreement between the square with corner-pieces and one with interleaved ends.

In conclusion, we would express our best thanks to the Physikalisch-Technische Reichsanstalt and the Bureau of Standards for their kind collaboration in the work.

APPENDIX I.

Extract from the Report of the Physikalisch-Technische Reichsanstalt, Charlottenburg, October 15, 1910.

(*At P.T.R. II.* 6,406.)

The five samples of cut iron sheets sent to the Reichsanstalt with the letter of July 4, 1910,† were tested by the wattmeter method with the Epstein apparatus at a flux density of B = 10,000, the power loss being measured for frequencies of 20, 25, 30, 35, 40, 45, and 50 ∼ per second, which enabled the total loss to be separated into hysteresis and eddy-current losses in the well-known way.

The wattmeter, voltmeter, and ammeter used were Siemens and Halske instruments with pointers; the frequency was determined by means of a Hartmann and Braun frequency meter, and the temperature was measured by a set of four copper-constantan thermo-couples, one junction of each being clamped between the sheets of each test bundle, while the other junctions were kept at a temperature of 0° C. The values of the resistance temperature coefficient was taken as 0·45

* *Journal of the Institution of Electrical Engineers*, vol. 46, p. 217, 1911.

† This letter was from the N.P.L. and contained the results of the first series of tests.

per cent. per ° C. for the ordinary material, and 0·1 per cent. per ° C. for the alloyed sheets.

The Epstein apparatus was provided with a special secondary winding.

The alternating current used was approximately of sine wave-form; the results were corrected to exact sine wave-form by calculation. The density 7·80 was taken tor samples 655 A, 657 C, and 663 E, in accordance with information from the N.P.L.; the densities of samples 659 B and 661 D were found, by weighing in water, to be 7·58 and 7·57 respectively.

The uncertainty of measurement of the total loss at the Reichsanstalt is estimated at about 1 per cent., while in the values for the hysteresis loss errors up to 2 per cent. are not out of the question.

(The results are given in Table I.)

APPENDIX II.

Department of Commerce and Labour.

Bureau of Standards, Washington.

Report on the alternating-magnetisation losses of five samples of sheet material used in an intercomparison with the National Physical Laboratory.

Sample.	Mass.	Specific Gravity.	B_{max}.	Frequency.	Alternating-magnetisation Losses (Watts per Kilogram).		
					Total.	Hysteresis.	Eddy Currents.
654 A...	1473	7·76	5,000	25	0·42$_2$	0·33$_0$	0·09$_2$
				50	1·03$_0$	0·66$_0$	0·37$_0$
			10,000	25	1·32$_0$	0·95$_5$	0·36$_5$
				50	3·37$_0$	1·91$_0$	1·46$_0$
656 C...	1532	7·72	5,000	25	0·44$_5$	0·36$_7$	0·07$_8$
				50	1·04$_5$	0·73$_5$	0·31$_0$
			10,000	25	1·37$_8$	1·04$_5$	0·33$_3$
				50	3·42$_0$	2·09$_0$	1·33$_0$
658 B...	1494	7·56	5,000	25	0·30$_0$	0·27$_5$	0·02$_5$
				50	0·65$_0$	0·55$_0$	0·10$_0$
			10,000	25	0·94$_0$	0·84$_0$	0·10$_0$
				50	2·08$_0$	1·68$_0$	0·40$_0$
660 D...	1480	7·55	5,000	25	0·27$_5$	0·24$_5$	0·03$_0$
				50	0·61$_0$	0·49$_0$	0·12$_0$
			10,000	25	0·87$_0$	0·76$_5$	0·10$_5$
				50	1·95$_0$	1·53$_0$	0·42$_0$
662 E...	1481	7·79	5,000	25	0·72$_0$	0·62$_3$	0·09$_7$
				50	1·66$_5$	1·24$_5$	0·42$_0$
			10,000	25	2·18$_2$	1·80$_3$	0·37$_9$
				50	5·12$_5$	3·60$_5$	1·52$_0$

The samples were tested in the form of a Lloyd square, and the losses separated as indicated in our Bulletin, vol. 5, No. 4, p. 468.

The losses were determined with approximately a sine wave of magnetisation and at a temperature of 25° C.

(*Signed*) W. F. HILLEBRAND,
Acting Director.

WASHINGTON, D.C.
January 9, 1911.

APPENDIX III.

The following are references to papers in which will be found full descriptions of the methods of test already mentioned as used in the three laboratories concerned:—

Gumlich and Rose, *Elektrotechnische Zeitschrift*, vol. 26, p. 403, 1905.

Lloyd and Fisher, *Bulletin of the Bureau of Standards*, vol. 5, p. 453, 1909.

A. Campbell, *Proceedings of the Institution of Electrical Engineers*, vol. 43, p. 553, 1909.

REMARKS ON THE METHODS.

For the sake of those readers who are not familiar with the methods we add a few explanatory remarks.

(*a*) In all the methods the magnetic circuit consisted of four bundles of strips assembled into a square with joints at the corners. In the P.T.R. tests these were butt joints between the respective bundles; in the B.S. and N.P.L. tests the bundles set up edgewise were clamped together at the corners with interleaved corner pieces as shown in Fig. 1, a system which shows experimentally very small magnetic leakage; in the tests marked "2 Interleaved," which are only given for purposes of comparison, the strips lay horizontally and were interleaved at the corners (imbricated). The relative dimensions of the various squares with respect to inner and outer periphery are shown in Fig. 2, X, Y, and Z respectively. As the magnetising turns were spaced evenly over the four limbs, the ratio of inner to outer periphery gives approximately the ratio of the maximum and minimum values of H applied to the iron. These ratios were approximately as follows:—

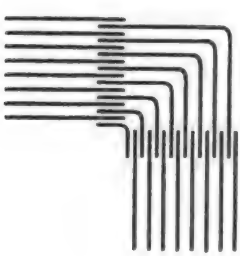


FIG. 1.

TABLE X.

Square	$\frac{\text{Inner H}}{\text{Outer H}}$
P.T.R.	1·13
B.S. / N.P.L.	1·06
Interleaved	1·50

In all the tests the energy losses in the material were measured by means of a wattmeter, the magnetisation being effected by alternating current. In the P.T.R. and the B.S. tests the $B_{max.}$ was kept constant and of sine wave-form, and observations were made for various values of the frequency n. It is found that, over a considerable

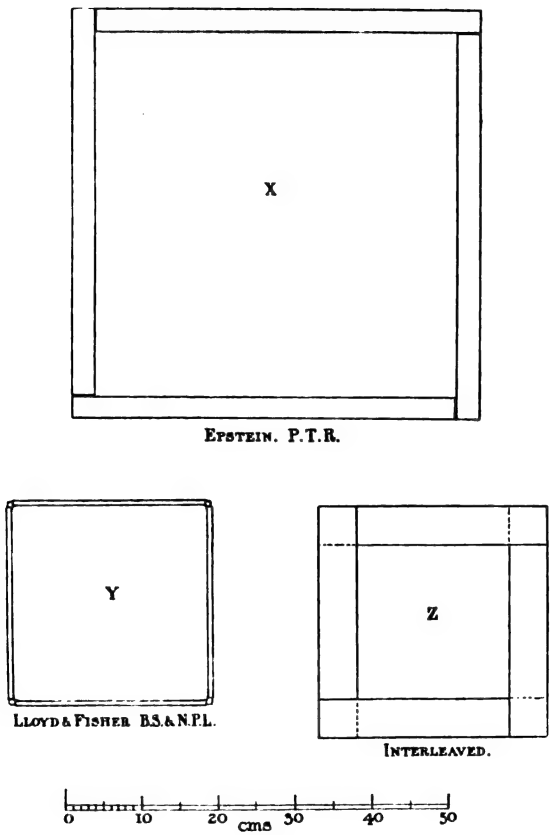


Fig. 2.

range of frequency, w_1, the watts per kilogramme per cycle is given very nearly by the equation—

$$w_1 = a + b\,n,$$

and the total loss at frequency n—

$$= a\,n + b\,n^2.$$

In separating the losses it has been assumed that $a\,n$ represents the hysteresis and $b\,n^2$ the eddy currents.

In the N.P.L. experiments in general n was kept constant at 50 ∿ per second, the mean value of the secondary induced voltage being also set to a constant amount. The form factor f of this voltage was varied within wide limits, being measured for each reading of the power lost. It was found that in this case the values of w_1 were in general given approximately by the equation—

$$w_1 = a' + cf^2,$$

and thus—

$$n\,w_1 = a'n + c\,n\,f^2.$$

For the separation of the losses, $a'\,n$ was taken as the hysteresis and $c\,n\,f^2$ the eddy-current loss.

TABLE XI.

Sample.	B_{max}.	Hysteresis Loss in Watts per Kilogram at 50 ∿ per Second.		Difference per Cent.
		Ballistic Method.	Alternating-current Method.	
A 1	5,000 10,000	$0\cdot71_7$ $1\cdot98$	$0\cdot68_9$ $1\cdot91_5$	$-4\cdot1$ $-3\cdot4$
C 1	5,000 10,000	$0\cdot71_6$ $2\cdot06$	$0\cdot73_6$ $2\cdot03_6$	$+2\cdot7$ $+1\cdot2$
E 1	5,000 10,000	$1\cdot23_4$ $3\cdot51_5$	$1\cdot24_6$ $3\cdot50_6$	$-0\cdot9$ $+0\cdot3$
B 1	5,000 10,000	$0\cdot55_5$ $1\cdot70_2$	$0\cdot54_6$ $1\cdot64_7$	$-1\cdot6$ $-3\cdot3$
D 1	5,000 10,000	$0\cdot49_7$ $1\cdot54_4$	$0\cdot48_5$ $1\cdot52_2$	$-2\cdot5$ $-1\cdot4$

The fair agreement between the results of the two methods of separation (with similar squares, B.S. and N.P.L.) shows that $a = a'$ and $b\,n = c\,f^2$, which is in agreement with the elementary theory.

At the N.P.L. the squares were also tested for hysteresis loss ($n = 0$) by the ballistic method. The results are given in the second column of Table XI., while in the third column are given the means of the alternating-current values obtained at the three laboratories (or in the case of $B_{max} = 5{,}000$ at the B.S. and N.P.L. $2\,p$). It will be noticed that the differences are in no case large.

Contractors for Advertisements:
Walter Judd, Limited, 5, Queen Victoria Street, Mansion House, E.C.

UNWIN BROTHERS, LIMITED, THE GRESHAM PRESS, WOKING AND LONDON.

MARCH, 1912. VOL. 48.

JOURNAL

OF THE

INSTITUTION OF

ECTRICAL ENGINEERS,

ORIGINALLY

HE SOCIETY OF TELEGRAPH ENGINEERS.

FOUNDED 1871. INCORPORATED 1883.

EDITED BY P. F. ROWELL, SECRETARY.

CONTENTS

N. SPON, LIMITED, 57, HAYMARKET, LONDON, S.W.

CHAMBERLAIN, 123, LIBERTY STREET, NEW YORK.

PRICE FIVE SHILLINGS

J. Henderson

JOURNAL

OF

The Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 48. 1912. NO. 212.

Proceedings of the Five Hundred and Twenty-seventh Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, 23rd November, 1911—Mr. W. DUDDELL, F.R.S., Vice-President, in the chair.

The minutes of the Ordinary General Meeting, held on 9th November, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members—

Francis Valentine T. Lee.
Sydney Louis R. Price.
Dr. Mario de Andrade Ramos.
Gilbert Rosenbusch.
Bernhard Wiesengrund.
Gottlieb Wuthrich.

From the class of Associates to that of Members—

Alfred S. Hampton.
Drogo Montagu.

From the class of Associates to that of Associate Members—

Harold Ashton.	Harry Melville Dowsett.
Colin M. Campbell.	Alfred Smyth.

From the class of Students to that of Associate Members.

Montague Butler Bean.	Herbert R. Hudson.
James Bowman.	Walter R. Mickelwright.
Vyvyan O. I. Davis.	Norman Miller.
Oscar Faber.	Thomas Geo. Partridge.
Ronald Grierson.	Elias Z. y Roxas.
Lewis William Hipwell.	Herbert G. Weaver.
Franklin T. Homan.	Percy D. Webb.

Joseph S. Westerdale.

The CHAIRMAN : I have to announce that immediately after the recess the Council addressed a letter to the Home Office in reference to some of the provisions of the Coal Mines Bill now before Parliament, and further offered, if agreeable to the Home Secretary, to appoint a deputation to wait on him and give any explanation which might be required on the points raised in the Council's letter. The Home Secretary invited the Council to appoint a deputation, and it was arranged that the Council's representatives should wait on Mr. Masterman, the Under Secretary of State for Home Affairs, this morning at noon, but owing to an alteration in the Parliamentary procedure in connection with this Bill, Mr. Masterman wrote yesterday that he was unable to receive the deputation, and it has accordingly been postponed indefinitely.

The following paper, "Automatic Reversible Battery Boosters," by R. Rankin, Associate Member (see page 283), was read and discussed, and the meeting adjourned at 9.55 p.m.

AUTOMATIC REVERSIBLE BATTERY BOOSTERS.

By R. RANKIN, B.Sc., Associate Member.

(*Paper received* 19*th October*, 1911; *read before the* INSTITUTION 23*rd November*, 1911, *before the* MANCHESTER LOCAL SECTION 28*th November*, 1911, *before the* SCOTTISH LOCAL SECTION 9*th January*, 1912, *and before the* BIRMINGHAM LOCAL SECTION 14*th February*, 1912.)

CONTENTS.

SUMMARY.

A brief mention is made of the object and scope of the paper, and this is followed by a short account of the uses and advantages of battery-booster plant, and the savings likely to be effected by its employment.

Boosters are classified in three leading divisions, (A), (B), and (C). Under Class (A) are described the plain differential, Pirani, Crompton

and Lancashire systems, with a discussion of their prominent features. Those described under Class (B) are the Highfield and E.C.C. systems.

A short discussion follows of the effect of main generator compounding, the action of line diverters, and of some causes of inaccurate working of diverter boosters in general.

The advantages of boosters controlled by external regulators over those of the diverter type, and the leading principle of their operation, are briefly mentioned. Such boosters belong to the next class (C), and those described are Entz, B.T.H., Taylor-Scotson, Tilney, Thury, and Brown-Boveri, while the systems of Lincoln and Bijur are also referred to. Rate of rise of field flux is dealt with, and the practical necessity of the provision of a checking control on quick-acting booster regulators.

Some methods of using battery-booster plant are then considered more fully, and several methods of adapting such plant to the control of winding gear are described.

The question of the employment of batteries on alternating-current systems is next treated, and some of the necessary plant described including regulator solenoids, the split-pole converter, and a special form of automatic exciter responsive to variations in alternating-current generator load.

Some figures are given relating to the plant at the Gary Steel Works, Indiana, U.S.A., and a short description is given of the Hucknall Colliery plant.

Practical results obtained by different boosters are given, and a short summary of conclusions finishes the paper.

Object and Scope of Paper.

Of automatic reversible battery boosters there are a great many types, each having its own special features, and it is the object of this paper to describe the principles underlying their operation, and so to compare them as to give engineers in general who are interested in the subject a means of settling which type is the most suitable under given conditions. The study of the essentials of the theories of the various schemes, as described in the paper, and the description of the means adopted to operate the machines in accordance with theory, should give an engineer a good idea as to whether the means employed are likely to lead to the ends sought, and the tables and charts of practical results obtained from the different classes of boosters show what may be expected from employment of systems of the various classes.

Outline of Uses and Advantages of Battery-booster Plants.

The important place which the secondary battery now occupies in the minds of central station and other engineers is indicated by the number of papers written on the subject both in this country and in others. Another indication is the number of battery and booster schemes advertised in the contract columns of the technical press, but,

besides those, there are, of course, many installations of this sort carried out without any advertisement. When it is considered that a saving in coal consumption of between 20 per cent. and 30 per cent. can be obtained through the installation of a battery and booster plant, in cases where the load is of a very highly fluctuating nature, and, say, 10 to 15 per cent. by the provision of a reliable automatic booster in cases where a battery is already installed without a booster, it will be seen that an exceedingly good case can be made out for this type of plant. The percentage savings given above are not at all exaggerated, but are results obtained in actual practice.

In order to obtain the maximum economy the battery-booster plant should equalise on the total load of the system on which it is installed. This, of course, it cannot usually do in the ordinary corporation electricity station where the 3-wire general supply system with earthed neutral has to be kept separate from the traction system with its rail return, but, even when equalisation is only carried out on the traction load, which is supplied by separate main generators, striking results can be obtained. They become more marked when the traction and general supply systems can be supplied from one set of generators, being connected by a link in the form of a motor-generator. For example, the mean traction load in a generating station may be taken by a suitable motor-generator, the motor being supplied from the outers of the 3-wire general supply system, and the generator being relieved of the traction peaks and dips by the battery and booster. With a booster which can be depended on as being practically instantly reversible the load on the motor-generator may be maintained almost constant, and the voltage of the 3-wire system remain unaffected by the power taken by the motor. Such an arrangement as this can very often be made the means of keeping the generating plant of a station working at a point of efficiency unattainable in any other way. It is, however, in the case of a works generating its own electricity for lighting, and for a very highly fluctuating power load, that the economy shown by a battery-booster plant attains its maximum. Economy is shown, not only in coal consumption, but in the cost of upkeep and repairs both of generating plant and lamps.

The disastrous effect of bad voltage on electric lighting needs no emphasising here. When it is considered that, in the case of carbon and metallic filament incandescent lamps, the candle-power varies approximately as the 6th and 4·4th power of the applied voltage respectively, it is readily seen that an ill-regulated voltage is fatal to satisfactory illumination and leads to short lamp lives, and that a good, steady voltage is practically a necessity. The writer knows of a large works in which the power to drive all machinery is generated by gas-driven generators, and yet the lighting is done by oil and gas. Previously electric light was employed, but it was given up as being unsatisfactory, both on account of the poor and variable illumination and the cost of upkeep. An inspection of the switchboard voltmeter immediately showed what all the trouble was due to, and this is a case where the

installation of a buffer battery with a reliable booster would undoubtedly give most satisfactory results. The owner of the place considers that electric light is inferior to gas or oil lamps fitted with suitable mantles, whereas the fact is that the electric light never really had a proper chance.

It may not appear, at first sight, that there is a great deal in having a little more or a little less illumination, but there can be little doubt that proper steady illumination in a workshop makes for greater efficiency and greater output. When each man can see at one glance what, with a slightly worse light, he might have to walk round and look for, the saving in time may come to be considerable, and, in addition to this, the general good effect on workmen of working under satisfactory conditions is a thing which very often does not receive the consideration it deserves.

The advantages of a battery as a standby need not be enlarged upon, as they are pretty generally recognised. This does not always mean that a battery should be large enough entirely to take the place of the generating plant for even a comparatively short period in the event of a breakdown, although this may sometimes be desirable, but, should the generating plant fail, the presence of a battery ensures at least that a light will be available.

The writer has had practical experience of cases where a battery has proved of immense advantage under such circumstances in preventing the stopping of important processes during temporary failure of the main supply. Especially where gas-driven generating plant is installed the certainty of a standby of this sort is of great importance. Light loads at meal hours and week-ends can often be handled by a battery, when, otherwise, the generating plant would be kept running very inefficiently.

Now that the lead-plate accumulator has proved itself to be a thoroughly reliable article, and makers are prepared to maintain it at 100 per cent. of its rated capacity for a long period and for a reasonable sum, the question of type of battery can usually be settled without much trepidation on the buyer's part, but the provision of a thoroughly reliable booster to work with the battery is very important. No matter how inherently good the battery itself may be, if it is not made to work properly by the booster, advantage cannot be taken of its good qualities. In fact, seeing that the accumulators made by the leading makers have now attained such a high standard of excellence, the question practically hinges on the booster, the success of this being the factor determining the success of the whole installation.

Classification of Boosters.

Broadly speaking, the boosters in use in this country belong to one of three classes :—

(A) Those in which the booster can be self-contained and operated by its own field windings independently of any outside controller.

(B) Those in which a so-called exciter is an absolute necessity, not merely for exciting purposes, but being an essential in the theory of the system.

(C) Those in which an external automatic regulator is used on the booster field, either directly or through an exciter, the latter not being an essential in the theory of the scheme.

CLASS (A).

Differential Booster.—The simplest type in this class is the simple differentially wound machine shown in Fig 1. In this case a coil A, carrying a portion of the total load current, and giving a booster voltage in the discharge direction, acts in opposition to a coil B, excited from the busbar voltage, and giving a field tending to produce

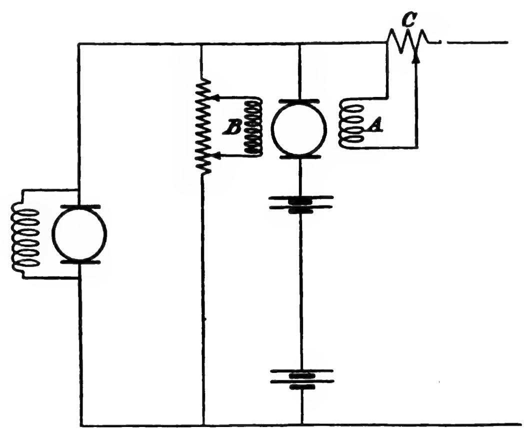


FIG. 1.—Plain Differential Booster.

a charge boost. The busbar voltage being assumed constant, the effect of coil B will be constant and definite for a definite adjustment of its regulator. The effect of coil A will just balance that of coil B when the line current has some definite value. The battery being assumed in a floating condition—that is, its voltage, with no current flowing into or out of it, being just equal to the busbar voltage—it is evident that the battery will be idle and the generator will supply the load when the effects of coils A and B just balance each other. An increase of load past the definite value required to make A balance B will cause A to overpower B, and a resultant booster voltage in the discharge direction will be produced. The battery will accordingly come to the assistance of the generating plant, and will give a discharge current of such a value that the total drop of voltage due to it, in the battery-booster portion of the plant, will just equal the voltage produced by the excess of the effect of A over that of B. With ideal working

and the diverter C properly proportioned, the discharge current would be practically equal to the excess of line current over that at which A and B were just balanced. A decrease in line current would have

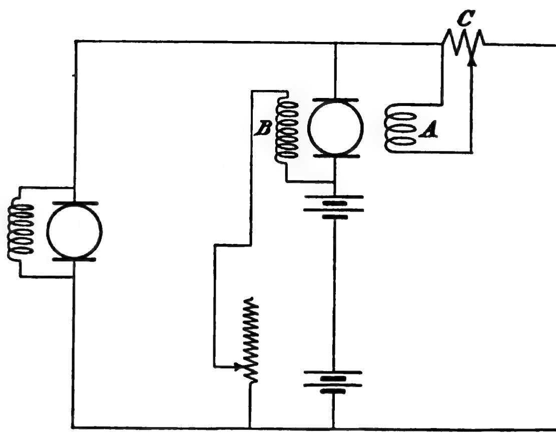


FIG. 2.—Pirani Booster.

an exactly opposite effect, B overcoming A, and the battery charging by an amount practically equal to the drop in line current.

The battery being continually on the charge or discharge, its

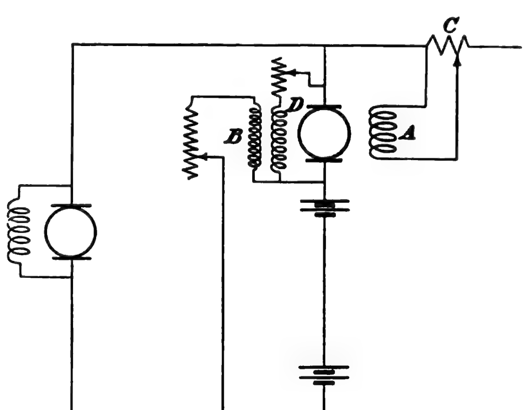


FIG. 3.—Crompton Booster.

E.M.F. will not remain at the floating value, but will vary considerably, as also will its resistance. For this, in the scheme under consideration, there is no compensation, and although the line current has such a

value that A just balances B, the battery may be discharging or charging, depending on whether its voltage is above or below the floating value. Owing to the battery resistance being variable, with a low state of the battery the same charge and discharge will not be obtained with a given variation in line current, as was obtained when the battery was in a floating condition. A similar remark applies when the battery is in a higher state of charge than that represented by the floating condition.

This action renders it impossible to obtain good regulation of the load on the main generating plant, and various methods are employed for the purpose of compensating automatically for the varying state of the battery. One method is illustrated in Fig. 3, which shows the skeleton diagram of the Crompton booster, but before this is described the Pirani system shown in skeleton diagram in Fig. 2 will be considered.

Pirani Booster.—As indicated in the figure, the shunt coil B is, in the Pirani system, connected across the battery. It was explained in the case of the simple differential booster that connection across the line voltage, which should be approximately constant, does not permit of the battery being charged and discharged in such a way as to keep the generator load constant, the varying state of the battery tending to check both charge and discharge. The differential booster is, however, quite stable in its action. The connecting of the shunt coil across the battery in the case of the Pirani booster certainly gets over the above-mentioned difficulty, but it introduces another trouble, which is quite as bad as the one eliminated, viz., that the action is unstable, and the battery tends to over-charge and over-discharge. That this is so is evident from the following consideration of the operation of the booster :—

For a given line current the shunt coil may be adjusted to balance the diverter coil. At this line current the battery should be idle, and the generator current equal to the line current. Assume that the line current rises, then :—

Diverter boost rises,
Battery discharges,
Battery potential difference falls,
Shunt current falls,
Discharge boost further increases,

and so on. There is nothing to limit this action and the battery tends to take the whole load off the generator. That is to say, there is nothing to compensate for the state of the battery. Now, when the line current falls, the battery (due to its having been discharging) will have a lower potential difference than at first, and hence the generator current which will just balance the shunt current must have a less value than the original. Hence the generator current has no definite value.

Assume that the line current falls, then :—

Diverter boost decreases,
Battery charges,
Battery potential difference rises,
Shunt boost rises,
Battery charges still more.

Again there is no limit to this action, and the generator may be heavily overloaded, or the battery injured through getting too great a charge. When the line current rises again it will take a greater generator current to balance the shunt coil boost than at first since, due to the charging, the battery voltage will be higher than before. Hence the action is indeterminate, and the value of the generator

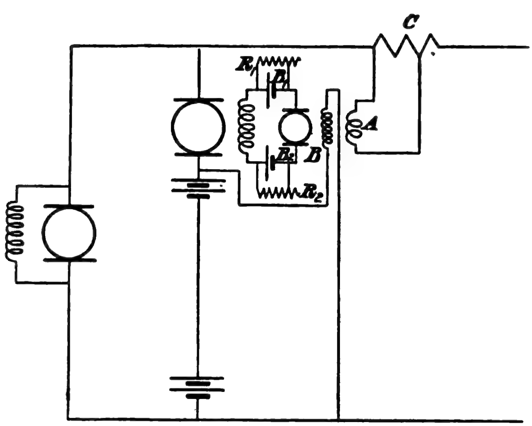


FIG. 4.—Modified Pirani Booster.

current very unstable, since there is no means of compensating for the varying state of the battery.

To limit the action described in the foregoing—for it cannot be eliminated—a valve, for example an iron-aluminium cell, is sometimes used, connected in the manner indicated in Fig. 4. B_1 and B_2 are iron-aluminium cells each connected in parallel with a resistance, the whole being in series with the booster shunt coil. Current can only flow through the cells in one direction, and, when it is flowing in the other direction, it is reduced by being forced to flow through the resistance in parallel with the cell.

To get a charging voltage, for example, the exciting field current would flow, say, through R_1, past B_1, through the booster field coils, and through B_2. The resistance R_1 would damp the current in this case ; with the current flowing in the opposite direction R_2 would damp the current.

The Pirani booster is, as shown in Fig. 2, identical with the Highfield semi-automatic booster, but neither is used to any great extent in this country.

Another disadvantage which is, however, shared by other boosters of this class, is that the amount of copper in the field is excessive, since it is not the actual ampere-turns on the magnets that are effective, but the difference between the series and shunt ampere-turns. The provision of an exciter with fields suitably wound and armature connected directly across a shunt coil on the booster as shown in Fig. 4, reduces the exciting copper on the booster field, but adds extra lag to the time of reversal which, in this class of booster, there is no means of overcoming.

Crompton Booster.—The Crompton booster (Fig. 3) is the elementary Pirani with the addition of a shunt coil D, connected across the booster

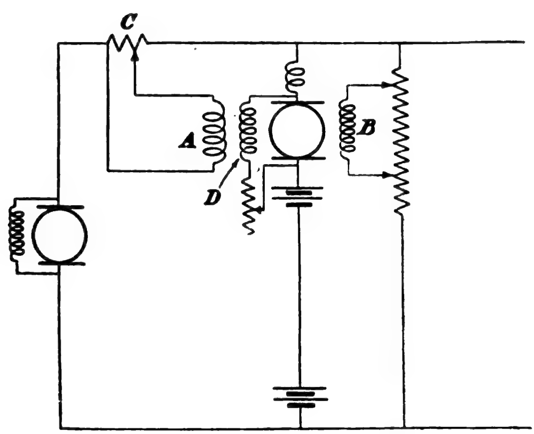


FIG. 5.—Lancashire Booster.

terminals, the object of this coil being ostensibly to compensate for the varying state of the battery; but it is difficult to see what gain is expected by the provision of this coil, as the undesirable features of the Pirani system are always present in the system, and the action of this additional coil simply augments the trouble referred to in the description of the latter. The action of the third coil will be understood from the following discussion of the Lancashire booster.

Lancashire Booster.—The Lancashire booster shown in Fig. 5 is of the differential type, the booster being provided with a third coil D, similar to that used in the Crompton system. Its presence here, however, is a distinct advantage. The coil, being connected across the booster terminals, is evidently excited by the difference between busbar and battery voltages, and it is designed in such a way that the field produced by it, on the booster, is always of such a value as to produce, in

the booster armature, a voltage exactly equal to the voltage across its own terminals. That is to say, the coil gives a booster voltage (assuming that every coil actually produces a voltage proportional to its ampere-turns) equal to the difference between battery and busbar voltages. Thus there is always, in the battery and booster portion of the circuit, a voltage equal to the busbar voltage, independent of the state of the battery. This leaves the coils A and B free to serve their proper purpose of regulating the booster charge and discharge, the two being balanced at normal generator load, and the total voltage in the battery-booster limb of the circuit being then equal to the floating value—*i.e.*, equal to the line voltage.

It should be observed that the diverter coil of the Lancashire booster carries a portion of the generator and not of the line current. The working of the system is as follows: At normal desired generator load the diverter coil and the separately excited shunt coil are set to balance each other. The self-excited shunt coil supplies the difference between the battery and line voltages enabling the battery to float without charging or discharging. An increase in line demand causes an increase in generator current, and therefore in diverter coil current, which starts the battery on discharge. The battery voltage accordingly drops, but the self-excited shunt coil compensates for this drop, the initial voltage due to the increase in generator current being available to draw current from the battery until the battery current attains the value at which the generator current returns to the normal.

Effect of Self-excited Coil of Crompton Booster.—To return to the Crompton booster, since the diverter coil carries a portion of the line current the boost due to it will go on increasing or decreasing so long as the line current is on the increase or decrease. If, as should be the case, the increase and decrease of line current are taken by the battery, the boost is proportional to the battery current, and hence to the drop in the battery, and may be made, as in the detailed description given later, equal to this drop. The third coil connected between the battery and line, however, will also tend to compensate for the drop, so that the drop will be over-compensated for, and, as already said, the unsatisfactory features of the Pirani booster made more prominent. Could the self-excited booster field coil be made to take care of the variation in battery E.M.F. due to its varying state of charge, independently of its resistance drop, the scheme would be all right, but unfortunately this cannot be arranged for.

Load Adjustment.—In diverter boosters generally the generator current should be adjusted to the desired value by an adjustment of the shunt coil B alone. The diverter should normally not be touched once it has been set to the proper value, although, in a Lancashire booster, both diverter and shunt regulator require to be adjusted if the best results are to be obtained. As will be explained later, there is, where the diverter is connected in the line circuit, only one correct value of the diverter resistance, if the best equalisation of load is to be obtained, but, in the case of Pirani or Crompton boosters which operate on a

defective theory, and in which the state of the battery is not properly compensated for, it may be of advantage to have a diverter of less resistance than this value, as this will tend to let the generator load rise and fall as the line load rises and falls. An adjustment of diverter resistance is, in this way, sometimes an advantage with a Lancashire booster or with a Highfield automatic booster, which will now be shortly described, as it makes the generator and battery share the load peaks, and allows the generator load to fall to some extent when the line load drops. The possibility of doing this is of value at periods when, to keep a steady generator current, the battery charges and discharges would be more than the battery could stand, and it is desirable

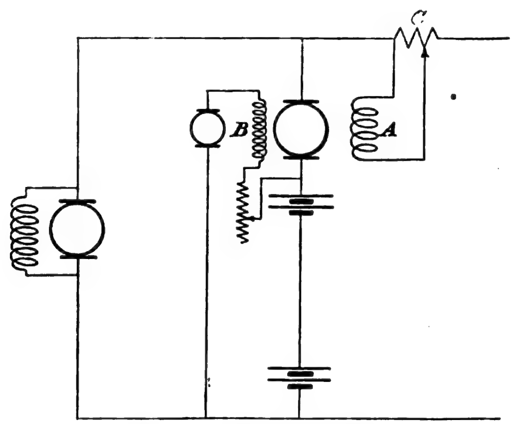


FIG. 6.—Highfield Booster.

to take advantage of the overload capacity of the main generating plant.

CLASS (B).

Highfield Booster.—The connections of the Highfield booster are shown in Fig. 6. In this case the varying state of the battery is compensated for by the employment of a small exciter. This is connected in opposition to the battery through the booster shunt coil, so that the latter is excited by the difference between exciter and battery voltages. The coil is designed in the same way as the third coil used across the terminals of the booster in the Crompton and Lancashire schemes, and the field it produces is of such a value as would produce a booster voltage exactly equal to the voltage across the terminals of the coil—that is, the difference between exciter and battery voltages. The diverter coil circuit being assumed open there is, therefore, always a voltage in the battery-booster portion of the circuit equal to battery voltage plus or minus the difference between battery and exciter voltages—that is to say, a voltage equal to the exciter voltage. The state of the battery

when in a normal stable working condition is therefore compensated for.

The facts that the exciter is a constant voltage machine, and that the booster shunt coil gives a booster voltage equal to the difference between battery and exciter voltages, make it possible, with a Highfield Booster, to run the battery and booster alone on the load, and yet have a constant line voltage automatically provided. The exciter voltage being made equal to the desired busbar pressure, current can be supplied to the load at normal steady voltage during the whole period of running with the generator shut down. Compounding over the steady value, if desired, can be obtained *viâ* the diverter. This is sometimes an advantage, and is one reason why a Highfield booster may be preferred to other boosters of the diverter type, although compounding

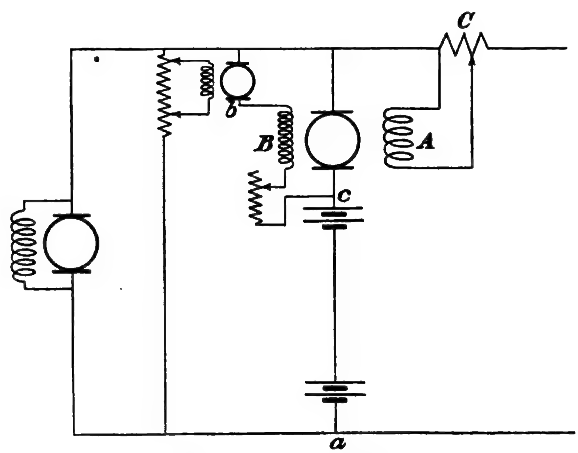


FIG. 7.—E.C.C. Booster.

viâ the diverter can be obtained with the others under similar circumstances.

With the circuit of the diverter coil closed there is the additional effect of it to be considered, and this always tends to give a voltage in the discharge direction, since the direction of the line current is constant.

With a given value of exciter voltage the battery and booster will just float on the busbars when the line current has such a value that exciter voltage plus diverter boost is exactly equal to busbar voltage. A rise of line current past this will cause an increase in diverter boost, which increase, with proper adjustment of diverter resistance, will just make up the drop of voltage in the battery-booster limb of the circuit when a discharge current is flowing approximately equal in value to the increase in line current. Similarly a decrease of line current will cause the diverter boost to decrease by an amount sufficient to allow a charg-

ing current to pass into the battery approximately equal to the fall in line current.

E.C.C. Booster.—The scheme known in Fig. 7 due to Strang, and worked by the Electric Construction Company, is another application of the principle adopted in the Highfield booster. In this, and in the Highfield system, the main point gained is that a voltage is always available and present in the battery-booster limb of the circuit, equal in value to busbar voltage minus diverter boost at the current which it is desired that the main generator should take. In the Highfield scheme the exciter voltage is adjusted to this value, and the generator current adjusts itself automatically to the proper value by means of the rise and fall of diverter boost above and below the difference between busbar and exciter voltages. In Strang's scheme the exciter voltage is made equal to the diverter boost at a line current equal to that which it is desired that the generator should take, and the booster shunt coil is again so designed that, if acting alone, it would produce a booster voltage equal to the voltage across the coil terminals. There is therefore always available in the battery-booster portion of the circuit, a voltage equal to battery voltage plus (busbar voltage minus exciter voltage minus battery voltage), that is, busbar voltage minus exciter voltage, or busbar voltage minus diverter boost at a line current equal to that desired on the generator. That this is so may be seen from the diagram; the potential difference between *a* and *b* is the algebraic sum of busbar and exciter voltages, or busbar voltage minus exciter voltage, that is, busbar voltage minus diverter boost at normal current. Between *a* and *c* the potential difference is the battery voltage, and the effect of the shunt coil is to add, algebraically, to this, in the battery-booster limb of the circuit, the difference between battery voltage and busbar voltage minus normal diverter boost, so that it is clear that the overall effect is to give an available voltage equal to busbar voltage minus normal diverter boost. The automatic action, after proper adjustments, is exactly the same as that in other line diverter boosters, the rise and fall of diverter boost, due to the rise and fall of line current, causing the battery to discharge and charge so as to relieve the generator of the fluctuations due to the peaks and dips in the load.

Effect of Compounding on Main Generator.—There is one disadvantage common to all diverter boosters, viz., they will not work so satisfactorily with over-compounded generators unless arrangements can be made to over-compound simultaneously both booster and generator to the same extent—not an easy matter—and this militates against their successful employment in stations where such generators are employed.

With an ordinary Highfield booster an increase in busbar voltage, due to over-compounding of the generator, cannot be compensated for, as the total available voltage in the battery and booster is equal to exciter voltage plus diverter boost, neither of which, assuming a constant booster speed, is affected by a variation in busbar voltage. The tendency is, therefore, for the generator load to be subjected to all the variations in line load. This effect is illustrated in Fig. 8 described below.

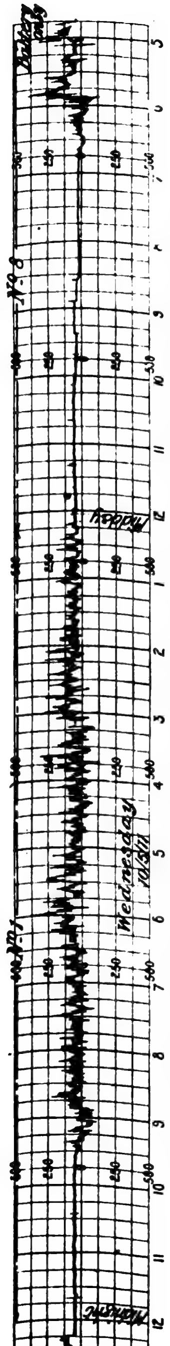


FIG. 8.—Diverter Booster Chart, showing the Effect of Generator compounding on Battery Current.

With a Lancashire booster the third coil gives in the battery-booster limb of the circuit an increase in available voltage corresponding to an increase in line voltage, but the current in the main shunt coil varies in direct proportion to the busbar voltage, and hence also does the current required to balance it, flowing through the diverter coil. As the mean load on the generator is settled by the current in the diverter coil required to balance the effect of the shunt coil, it is evident that it will be affected by this action, which, it may be observed, is cumulative. Similar remarks apply to the E.C.C. scheme.

Fig. 8, which has already been referred to, is a reproduction of a battery current chart obtained in an ordinary day's working of a diverter booster in a traction station, where the generators are compound. In the very early morning the battery is used to supply the cars until the demand grows heavier, when an over-compounded generator is started up. For a short time it will be noted that the battery does a good deal of work assisting the generator, but it then ceases, the battery current chart being practically a straight line. The reason is that during the period when the battery was equalising more or less in a proper manner the generator load was high, the machine working on or over the bend of the external characteristic curve, the high value of generating current being rendered necessary by the large tramway load during this period. The falling off of outside load necessitated a reduction in generator current bringing the load well back on the external characteristic curve to a part where the over-compounding effect of the generator had full play to keep the battery from taking its share of the load.

The set referred to was then shut down and a large set run up, this set not being so heavily over-compounded as the other, and, as a consequence, the battery and booster did a considerable amount of work until, the generator current being set at a high value, the battery became highly charged and regulation again became practically non-existent. This was due to the fact that the variation in the voltage of the battery-booster portion of the circuit, caused by the rise and fall of diverter boost, was lost in causing a variation in

battery E.M.F. and not in the form of a C R drop, as it would have been had the battery been in a stable—not necessarily constant—working condition; in fact, part of the voltage of the battery when in a highly charged condition may be said to have had no power behind it on discharge, and, on charge, required no power to build it up. This, of course, may be seen in the ordinary charge and discharge curves of any storage cell. It would have been difficult to obtain a chart showing more clearly the limitations of diverter boosters than that reproduced in Fig. 8, although this one was taken simply in the ordinary working of the station and without any view to its being reproduced here.

As, however, the object of a booster is to keep a constant load on the generating plant there is little reason, provided the booster is otherwise capable of giving satisfactory results, why the generators should not be run shunt, or with some of the compounding cut out, so as to make them level-compounded while the booster is in operation. The compounding can be used, if desired, when the generator is running alone on the load. Compounding where a diverter booster is employed, if absolutely necessary, could be obtained by the use of an ordinary series line booster. In a paper read before the Manchester Local Section in 1901, the late Mr. G. A. Grindle stated that he was of the opinion that the battery and booster should take entire control.* He went the length of saying that the engine should be run without a governor on a constant steam pressure and valve admission, and considered that a good deal of the variation that occurs when a battery and booster are regulating is due to the governor of the engine attempting to make the engine follow the load, instead of leaving the battery to deal with the variation. Evidently over-compounding of the generators has a similar but more pronounced effect, as already described.

The presence of a heavy flywheel on the engine also affects the quality of the results obtained with some boosters in the same way, a fairly marked difference in regulation being sometimes obtained with different generating sets.

Although not every one will agree with this view of the matter, there is a good deal in it. Certainly better charts of generator load can be obtained if the generator has a pronounced tendency to refuse to take more load, enabling the battery and booster to show to the greatest advantage. However, if automatic compounding is desired, so that the station voltage rises and falls in accordance with the line demand, boosters of Class (C) should be used and compounding of the generator effected as indicated later when those are being dealt with.

Action of Line Diverters.—It has already been said that for proper automatic regulation of generator current, when the diverter is in the line circuit, there is only one correct value of diverter resistance, and that the diverter should be adjusted to this unless the variations of load are more than the battery and booster can handle, and it

* *Journal of the Institution of Electrical Engineers*, vol. 30, p. 1098, 1909.

is desirable to make use of the overload capacity of the main generating plant. Adjustment of generator load should all be made on the shunt coils. That this is so will be seen from the following remarks.

When the line current has its normal value, the battery and booster should be idle, and, according as the line load falls below or rises above this value, the booster should cause the battery to charge or discharge. The working boost is the direct result of the amount of increase or decrease of the line current. With perfect load regulation and equalisation this increase or decrease would be exactly equal to the battery current. With this ideal regulation the generator current, and therefore its voltage, would remain absolutely steady. The battery and booster limb of the circuit has therefore to act as a level compounded unit, the compounding effect being obtained *viâ* the diverter. Every increment of line current adds its quota to the voltage of battery plus booster, but not to the generator voltage, seeing that the increment is drawn from the battery. Of course, the first increment of line current must come from the main generator, since the battery plus booster voltage cannot be affected until an alteration has taken place in the line current, but, unless the generators are over-compounded, this increment, in itself, cannot hinder the battery and booster in their working; where the generator is heavily over-compounded, however, this initial increment of the line current, equivalent to an increment of generator current, by causing the generator voltage to rise, may quite defeat the efforts of the booster to make the battery work (see Fig. 8).

The resistances of the battery and its connections being assumed constant and the booster without armature reaction, the drop of voltage in the battery and booster part of the circuit will be strictly in proportion to the current taken from the battery. The compensating increment of voltage from the booster diverter coil should therefore be directly proportional to the battery current, and since the increment of diverter drop, and therefore of diverter coil current, is directly proportional to the increment of line current, that is to say, to the battery current, this result is evidently obtained, provided that the automatic working booster voltage is obtained on the straight part of its open circuit curve, where machine voltage varies directly as field current. This being arranged for, there is therefore a strict proportionality throughout, and hence, when the diverter has been set to give the correct boost for one load variation, it will give the correct boost for all variations. Obviously the effect for a decrease of line current is similar to that for an increase, the drop in diverter boost in this case being such as to produce a drop in booster voltage exactly equal to the resistance drop due to a charging current flowing into the battery, equal to the drop in line current.

The use of interpoles on boosters decreases armature reaction, but, in practice, a compounding coil in series with the booster armature is always found desirable with diverter boosters. The drop of voltage in

the booster armature being compensated for in this way, it is possible to use a somewhat less expensive diverter.

Some Causes of Inaccurate Working.—It is impossible to make any exact calculation of the resistance of a diverter as used above, but an approximate value is easily calculated. Some margin should be allowed for increase of battery resistance with age. The fact, already stated, that the resistance of the battery is not constant, even with the battery in a stable working condition, but varies with the varying state of the cells, is one reason why the working of line diverter boosters can never be truly accurate. If the resistance of the part of the diverter in use is greater than the correct value, the battery will tend to lift the load off the generator on discharge and tend to overload it on charge. A similar effect is produced if shunt coils which should have a voltage gradient of unity set up too strong a field. Consequently the best method to follow is to design those shunt coils for too strong an effect, and introduce a booster field resistance to reduce the action to the proper point.

Variable resistance of field coils with varying degrees of heating is another cause of inaccuracy of working.

Besides the foregoing, the use of a diverter, itself practically non-inductive, in parallel with a highly inductive field coil, must produce a pronounced tendency to sluggishness of action in all boosters in this class. When a demand for current comes on, the currents flowing in the parallel circuits of diverter and field coil, will not assume values in accordance with the relative resistances of the two circuits for some time, but the diverter will get more than its due share and the field coil considerably less. This is an inherent defect which must inevitably show itself in cases where the fluctuations in load are very rapid. It will be recognised as a point that has to be considered in connection with the design of interpole machines.

A consideration of the fundamental equation for the growth of current in an inductive circuit gives an expression for the relative rates of variation in current. The equation is—

$$E = c\,R + L\frac{dc}{dt}$$

$E =$ applied voltage.
$R =$ resistance.
$L =$ inductance.
$c =$ instantaneous current at time t.

Integration of this gives the result—

$$C = E/R\left(1 - \epsilon^{-\frac{Rt}{L}}\right).$$

Substitution of this in the original equation gives—

$$\frac{dc}{dt} = \frac{E}{L} \epsilon^{-\frac{Rt}{L}}$$

or rate of increase of current is proportional to—

$$\frac{1}{L \cdot \epsilon^{\frac{Rt}{L}}}$$

Hence—

$$\frac{\text{Rate of rise in diverter}}{\text{Rate of rise in diverter coil}} = \frac{L_c}{L_d} \frac{\epsilon^{\frac{R_c t}{L_c}}}{\epsilon^{\frac{R_d t}{L_d}}}$$

$$= \frac{L_c}{L_d} \cdot \epsilon^{\left(\frac{1}{T_c} - \frac{1}{T_d}\right)}$$

where suffixes c and d refer, respectively, to coil and diverter, and T = time constant.

It will be seen that $\frac{L_c}{L_d}$ may be a pretty large number, and that although the second factor has a negative index, the current may initially rise in the diverter at a very much higher rate than in the coil in parallel with it. The same result is obtained by a consideration of the rate of fall of current.

Class (C).

In this class of booster control is usually made to depend on small variations in the generator current which it is desired to regulate, these small variations being turned to account to prevent the occurrence of larger variations. The idea is somewhat akin to that employed in the hit-and-miss system of governing a gas engine. The regulation does not depend on exact design, but on the rapidity with which the regulator can act, and, as will be seen from the following discussion, arrangements can be made to ensure very rapid action indeed.

Most makers of diverter boosters consider it necessary to laminate the entire booster field system; in fact, Mr. Turnbull, in a paper on the Lancashire booster, read before the Newcastle Local Section,* says that only thus can this booster be made to respond to the variations in line current. The chart of generator current illustrating his paper (Fig. 28) gives some idea of the quickness of reversibility of this booster, and it may be fairly assumed that this chart exhibits the best results that can be obtained from this type of booster, and may be taken as being fairly representative of the best results obtainable from diverter boosters in general. With boosters controlled by a quick-acting regulator there is no necessity whatever to have such a refinement as

* *Journal of the Institution of Electrical Engineers*, vol. 36, p. 591, 1906.

lamination of the field system, even where an extra link is introduced in the form of an exciter.

Entz Booster.—The simplest system is that invented by Entz, the prominent feature of which is a piece of apparatus called the Entz carbon regulator. The connections are as shown in Fig. 9, where an exciter is shown connected across the booster field, the field of the exciter being controlled by the carbon regulator. The latter consists of two sets of piles of carbon discs A and B, connected in series across a section of the battery; in the figure it is, for simplicity, shown across the whole battery. The junction of the two sets is connected, through the exciter field C, to the middle point of the section of the

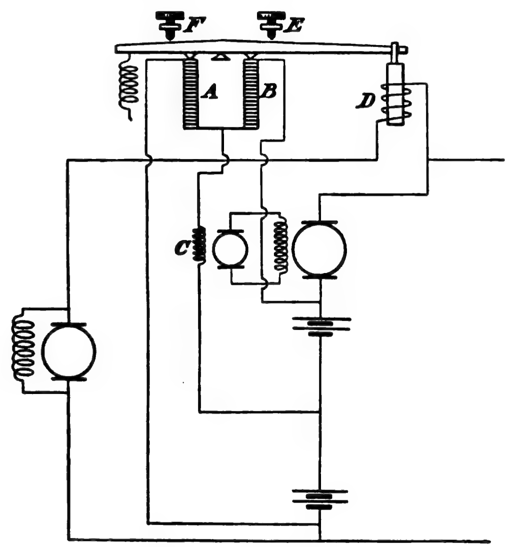


FIG. 9.—Entz Booster.

battery in use. The generator current which it is desired to regulate is carried round a solenoid D, provided with an iron core suspended from the end of a lever arranged with a pressure transmitter for each set of carbon piles. The pull on the solenoid core is opposed by a spring as indicated in the sketch. The two sets of carbon piles being in series across a section of the battery, the potential differences across them will be directly proportional to their resistances, which are varied by the movement of the regulator lever. The potential of the middle point of the regulator, that is, the junction of the two sets of piles, relative to the potential of the middle point of the section of the battery in use, will therefore obviously vary with the relative resistances of the two sets of piles, and a current will flow through the exciter field when the resistances of the two sets are unequal, the direction

of the current depending on which of the sets of piles has the greater resistance.

When the pull exerted on the core of the regulator solenoid is equal to the tension of the spring with the lever in the horizontal position, the resistances of the two halves of the regulator are equal. This will be the case when the line current has a certain definite value, and the battery, if in a floating condition, will then be idle. Should the line current increase the generator current will increase, but a small increase of solenoid current will disturb the balance between the pull on the core and the tension in the spring. Pressure will accordingly be put on the set of piles adjacent to the solenoid, with the result that a current will flow in the exciter field in such a direction as to give a discharge voltage on the booster. This, by drawing current from the battery, will prevent a further increase from getting back to the generator, and, although the regulator is designed to give, momentarily, a voltage for excitation purposes in excess of that actually required, overshooting of the correct discharge checks itself, because immediately the battery discharge begins to relieve the solenoid of the small increment of current, the pull on the solenoid core begins to fall, and consequently the pressure on the compressed set of carbon piles also falls, which pressure is directly responsible for the discharging voltage of the booster.

The effect of a fall in line current is to enable the spring to pull the lever down on the other set of piles, and the direction of current in the exciter field is now such as to cause a charge boost. Should the battery not be in a floating condition the regulator will automatically exert a pressure on the proper set of piles, so as to keep the battery idle when it should be so. The overall effect is to give a practically steady generator current, the variations up and down from the mean value being small. Excellent results are being obtained with this system, generator current charts taken in traction stations dealing with very highly fluctuating loads having an appearance more like good voltage than current charts.

The travel of the lever, and hence the corresponding charge and discharge battery currents, can be limited by stops E and F placed above it. This allows the best possible regulation to be obtained so long as the line fluctuations are within the capacity of the battery and booster, and, when the fluctuations are excessive, they are thrown back on the main generator and advantage taken of its overload capacity. It may here be noted that the generating plant is only called upon to share in the fluctuations when these exceed the capacity of the battery and booster, whereas, if it is desired, in the case of a diverter booster, to make the generator share the fluctuations, the diverter resistance has to be adjusted to a low value and the sharing process goes on all the time, and not merely when the fluctuations are beyond the capacity of the equalising plant.

Since control is dependent only on the generator current, over-compounding of the generator can have comparatively little effect on

the regulation, the regulator automatically supplying any extra booster field required to meet the compounding, and, if it is desired, the line current or a portion of it can be carried round a compounding coil on the main generator in order to raise the busbar voltage at times of heavy peaks, without its being necessary to provide any special arrangements on the booster. This has been done in practice with the Entz booster.

It will be seen that adjustment of the generator current to any desired value is an exceedingly simple matter, as, of necessity, the generator current must automatically assume such a mean value as will hold the lever in a position such as will leave the resistances of the two sets of piles equal. Hence the only adjustment necessary is the tightening or slackening of the regulator spring, and this simply involves the turning of a small hand-wheel.

A notable feature of the Entz system is its simplicity. There is no complicated system of field windings to be designed in accordance with exact theory, and requiring patient adjustment on site, and consequently exceedingly little trouble is experienced in putting it to work.

An important property claimed for this regulator has already been mentioned, viz., that when the balance between solenoid pull and spring tension is disturbed the result, due to the sensitiveness of the piles to change in pressure, is an exciting voltage for the exciter field, and hence an exciter armature voltage, in excess of that actually required. This compels the booster field to build up to the required value very rapidly. The makers claim a 3-times effect of this character on the average. The exciter field circuit has a definite time constant, and, whatever voltage is applied to it, the current in the field coil will attain the final value corresponding to this voltage in a definite time. This is to say, the time between application of voltage and attainment of the corresponding final value of current is the same whatever the value of the applied voltage, although the final values of the current will be in direct proportion to those voltages.

Rise of Field Flux.—Assuming that, to meet a given line peak, a voltage E is required across the exciter field, and a voltage 3 E is applied, the current in the field will attain a value equal to the final value which E would produce in one-third or a smaller portion of the time that E would take. The curves shown in Fig. 10 illustrate this point. For example, the current with an applied voltage E takes 2 seconds to rise to 0·86 ampere, but with an applied voltage 3 E it attains this value in less than ⅓ second. The curves are plotted from the equation—

$$C = E/R\left(1 - \varepsilon^{-\frac{Rt}{L}}\right)$$

R and L being the resistance and inductances of the circuit respectively, E the applied voltage, and C the current at any time t after the application of the voltage. For convenience E/R and R/L have

been taken equal to unity, the graphs therefore representing the functions $Y = 1 - \epsilon^t$ and $Y = 3(1 - \epsilon^t)$ respectively. As instant reversibility is what is aimed at in every automatic battery booster, it will be seen that the possession of this property is an exceedingly strong argument in favour of the Entz and similar systems.

B.T.H. Boosters.—Since the Entz system was invented various other systems have been introduced employing the same principle, viz., the variation of either of two resistances connected in series across the battery or a section of it, and having the controlling field connected between the junction of the resistances and the middle point of the part of the battery in use, this variation of resistance being made responsive to small variations in the generator current which it is desired to keep steady.

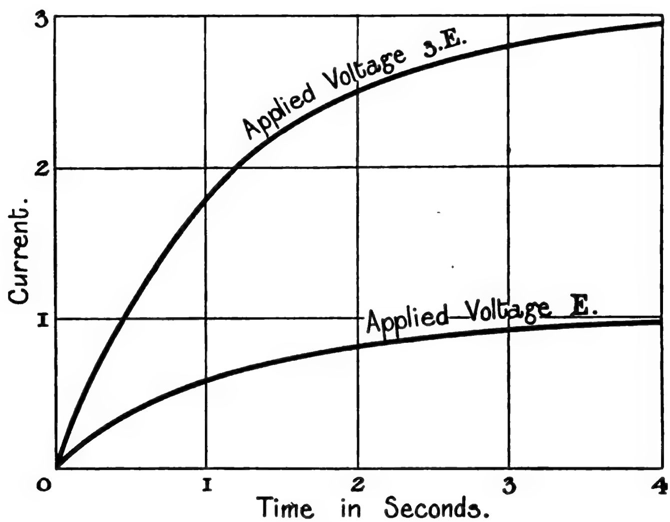


FIG. 10.—Rise of Current in a Field Circuit.

The well-known Tirrill regulator has been employed in this way. Originally this regulator was used for voltage regulation, its operation being responsive to small variations in the voltage which it was employed to steady. Its application to the control of battery-booster plant is shown in skeleton form in Fig. 11. It will be seen that the scheme of connections is the same as that of Entz, the two sets of carbon piles being replaced by two resistances, and the large solenoid by a diverter and a small solenoid. Variation of the potential of the junction of the resistances, relative to that of the middle point of the battery, is obtained, not by variation of the resistances, but by their being entirely cut out by short-circuiting. Operation of the system is responsive to small variations in generator current reflected in the main solenoid. With the

contact A occupying a position between contacts B and C, which will be when the spring is balanced by the pull on the magnet of the main solenoid D, the two relays E and F are energised, and both pairs of the corresponding short-circuiting contacts G and H are open. The resistances R_1 and R_2 being equal, there is therefore, under those conditions, no current in the booster field. A sufficient increase of solenoid current over that required to balance the tension in the spring causes the middle and upper contacts A and B to close. The relay coil on magnet E is therefore short-circuited and de-energised, and the contacts G close under the action of the spring shown in the Fig. This, by short-circuiting the resistance R_1, throws the booster field directly across half the supply voltage, and produces a booster voltage tending to discharge the battery, but immediately the discharge

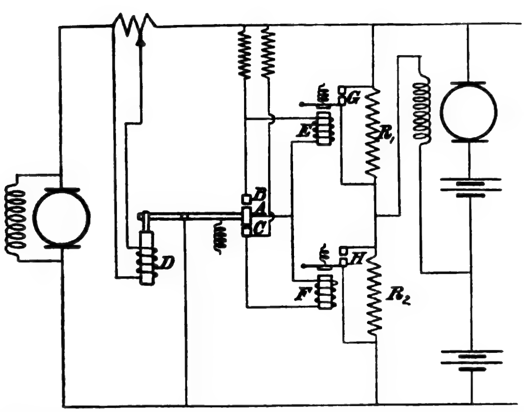


FIG. 11.—Skeleton Diagram for Booster controlled by Tirrill Regulator.

exceeds the value required to bring the generator current back to its normal value, the main spring overpowers the pull on the solenoid core, and the middle and lower contacts A and C close, giving a charging tendency by means of F in a manner similar to that indicated above. Obviously the middle contact is never at rest, as, in order to get quick reversal of booster field, the complete cutting out of the resistances is designed to give an overshooting effect similar to that noted in connection with the Entz regulator.

Fig. 9 shows the whole of the apparatus used in the Entz system, but in the Tirrill scheme the outline shown in Fig. 11 is insufficient to give satisfactory practical results, it being necessary with the Tirrill regulator, as with most other regulators designed to give an overshooting effect, to adopt some principle of auxiliary checking control. Operation, as it is described in connection with Fig. 11, is obtained by overshooting of battery current in the charge and discharge directions. It is necessary to check this by opening the contacts A and B or A and C, the

closing of which causes the discharge and charge, before the battery current has time to overshoot, at the same time taking advantage of an overshooting booster exciting voltage in order to build up the booster field rapidly; the exciting voltage is allowed to overshoot, but the action is checked before the booster field produced exceeds the required value. The booster voltage lags behind the corresponding movement of the regulator, which, by design, corresponds to an effect in excess of that actually required. At the time, therefore, that the booster voltage attains the correct value, the regulator is in what may be termed a too advanced position, and an over-regulating effect would be the result were steps not taken to prevent it. The required checking effect is obtained by the use of what are termed "floating contacts," as illustrated in Fig. 12.

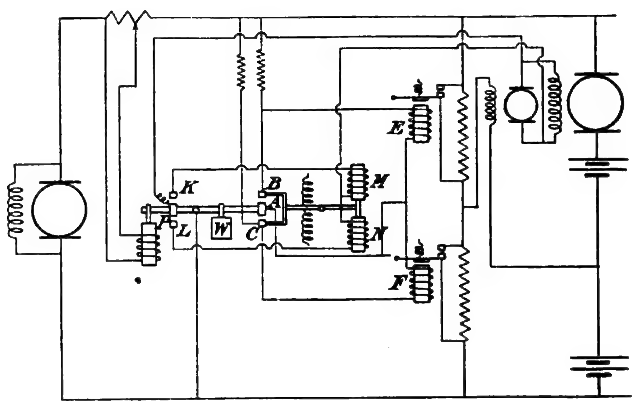


FIG. 12.—Control by Tirrill Regulator with necessary Checking Action.

In this case the booster is excited from an exciter, the field of which is controlled by the regulating apparatus. The contacts B and C are mounted on a spring-controlled pivoted lever, on which are also mounted the cores of two solenoids M and N, which are energised by the exciter voltage at the proper time through the contacts K and L. The main lever, at the end of which is suspended the core of a solenoid energised by a portion of the generator current, is provided by a weight W to balance the pull on the solenoid at the desired generator load, and a contact P working between K and L, as A works between B and C. When the main lever is in the horizontal position A is clear of B and C, and there is no current in the exciter field. An increase in generator current causes A to rise and make contact with B. This de-energises E, and the exciter field is excited in such a way that the exciter voltage causes the booster to give a voltage in the discharge direction. It will be noticed that as A goes up and touches B, P goes down and touches L, energising the solenoid N from the exciter voltage. The action of N

is to tend to raise B from A, and the spring opposing N is adjusted so that this action occurs at a suitable moment. The opening of A and B has, of course, the effect of checking the discharge boost earlier than it would be checked if B were stationary. The checking may, however, be too early, but in that case A will follow up B and again make contact, B again retreating when the exciter voltage attains some somewhat higher value, due to the fact that the tension in the spring opposing N increases directly with its extension. This following-up action of A is due to the fact that the pull on the main solenoid core is balanced by a weight W and not by a spring, for so long as the moment of the pull on the core about the hinge is greater than that of the pull of gravity on the weight W, so long will the lever move. Should W be replaced by a spring the movement of the lever would increase the tension of the spring, and a continued lever motion could only be obtained by a continued increase in the current in the solenoid.

Hence, so long as the generator current has a value above that desired, the contact A will follow B, the retreating action of B preventing the battery discharge current from overshooting, although the exciter voltage is allowed to overshoot for the purpose of getting quick action. The movement of B must obviously take place in a period of time less than the interval which would elapse between the moment when the exciter has a definite voltage and the moment when the battery discharge would attain its corresponding value. The result is a very quick vibration of the contact B.

A similar effect through the other set of relays is obtained when the generator current decreases, resulting, in this case, in a charge boost.

Checking Action in Entz Regulator.—It should be noticed that no type of auxiliary checking mechanism is used with the Entz regulator, this being due to the sensitiveness of the carbon piles to changes of pressure. In fact, the Entz system possesses the advantages of both hit-and-miss and rheostatic control. When a pair of contacts on the Tirrill regulator are open or closed the corresponding resistance is either all in or all out, and "all in" and "all out" both mean over-regulation, whereas, with the Entz regulator, the variation of resistance, although very rapid, is also gradual, and when the battery current, caused by a slight increase or decrease in generator current, begins to reduce that increase or decrease, the reduction immediately causes an alteration in the pressure on the piles, which pressure was due to the slight increase or decrease in generator current first mentioned, and which actually was the means of producing the battery current. With the carbon regulator, therefore, rapid action is obtained together with the very important advantage of extreme simplicity.

Taylor-Scotson Regulator.—Another regulator of the Tirrill type is that used in the Taylor-Scotson system. In the application of the Tirrill regulator a resistance in series with a field winding is open- and short-circuited alternately, but, in the Taylor-Scotson scheme, the open- and short-circuiting operation is performed directly on a field winding itself. The regulator is mostly used for voltage regulation, and, so far

as the author knows, has not been applied to the control of battery-booster plant in the ordinary way, but the action is made to depend on the rise and fall of line voltage at some point in somewhat the same way as the Thury regulator, described later, is employed. Of course, the other external regulators could also be employed in this way.

Fig. 13 shows diagrammatically how this regulator may be utilised. The battery booster is of the hand-reversible type, and its voltage may be regulated and reversed by means of a potentiometer type resistance and a suitable switch in the usual manner. In series with the booster field there is a differentially wound exciter E, the fields of which are equal and are controlled by the vibrating contact A shown between the fixed contacts B and C. The position of A is controlled by means of a spring and a solenoid D, which is connected across the voltage which it is desired to control. This may be the voltage at the end of a

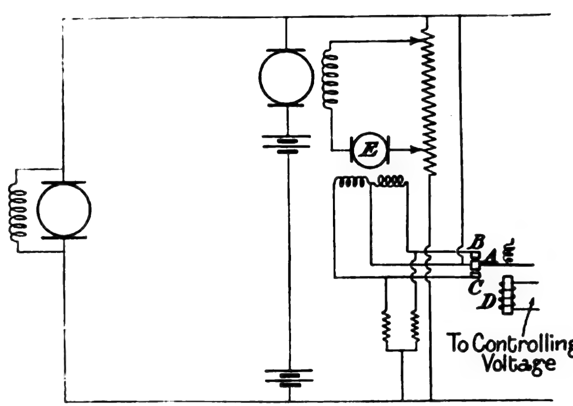


FIG. 13.—Control by Taylor Scotson Regulator.

feeder. With A in its mean position the exciter fields completely neutralise each other, being excited equally from the line voltage. An increase or decrease in the solenoid voltage short circuits one of the fields, and the exciter gives a voltage in such a direction as to decrease or increase the booster voltage.

In practice the regulator requires to have a checking apparatus to prevent over-regulation, similar to that employed with the Tirrill regulator, but the diagram shows the main principle employed in the scheme.

Tilney Booster.—The Tilney booster shown in Fig. 14 is classed as an externally regulated set.

Referring to the figure, a potentiometer type booster field-regulating and reversing switch is shown operated by a small motor. The armature of this motor is connected through a resistance across the line voltage, and its field is wound differentially, one coil being excited

from the busbars and the other carrying a portion of the generator current. The shunt coil is set so as to balance the diverter coil at the desired generator current. When the coils exactly balance each other the motor armature is stationary. An increase or decrease in generator current, due to an increase or decrease in line demand, disturbs the balance of the coils and gives a resultant motor field and a consequent torque, and the armature accordingly revolves and regulates the booster field, until the battery current assumes the value necessary to bring the generator current to the correct value again.

This method of regulating the booster field follows the hit-and-miss principle already described, but the differential method of winding, as already explained, does not make for rapidity of action, and a further lag is introduced by reason of the fact that what is simply an ordinary

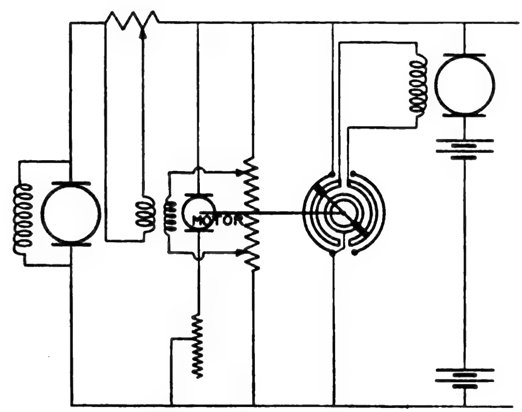


FIG. 14.—Tilney Booster.

field-regulating and reversing switch is used, with its attendant inertia and brush friction.

As will be seen, there is no provision made for over-regulation, and it is rather difficult to see, in view of the fact that a checking arrangement has to be provided with all similar and successful regulators as an absolute necessity, that the results obtained on a rapidly varying load will be satisfactory.

As a matter of fact, the vital importance of this checking action is not properly appreciated, and there are many other regulators patented of which little is heard, probably due to the fact that such a control has been omitted.

Clearly this type of regulator will not work so well with compound as with shunt generators, the control being dependent not only on variations in generator current, but also on the value of the line voltage.

Thury Booster.—The Thury voltage regulator has been applied to

the control of battery-booster plant, an outline of the scheme in which it is employed being shown in Fig. 15. The question of over-regulation, and the provision of a checking action arises in connection with this system as in the Tirrill and other external regulators. The action of the regulator is responsive to variations in busbar pressure, and a rise or fall of voltage from the desired value causes the regulator to act, and a booster voltage in an appropriate direction is the result.

The booster is fitted with a series field coil and a shunt, the latter being excited from the battery through a potentiometer resistance and switch R, the arm of which is rotated by toothed wheel A. This toothed wheel is rotated in either direction by one of the pawls B and C, which operate in conjunction with the triggers D and E, which in turn are actuated by the knife-edged projection F on the pivoted lever G, the travel

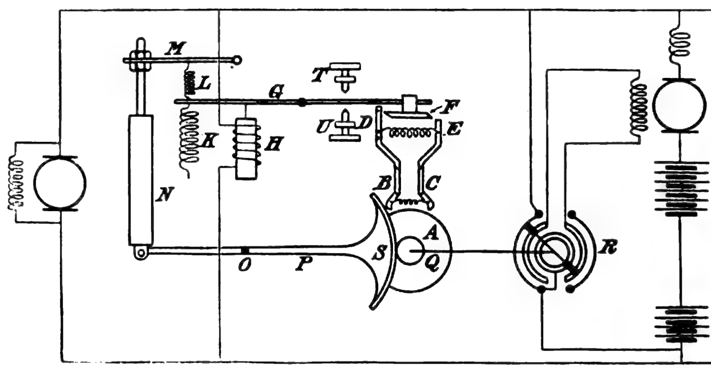


FIG. 15.—Thury Booster.

of this being limited by T and U. On the side of the pivot of G, remote from the triggers, is a solenoid H, which is connected across the busbar or other voltage which it is intended that the battery charge and discharge should keep constant, the action of the solenoid coil being to tend to raise the iron core, this lifting action being opposed by the spring K. L and M are two more springs, the former a spiral in tension and the latter flat. N is an oil dashpot whose piston has an adjustable opening in it, and P is a lever pivoted at O and rocked round O by a toothed wheel Q and rack S.

The triggers D and E and the pawls B and C are mounted on an arrangement which is, by the action of a small motor not shown in the figure, kept rocking backwards and forwards. The triggers are each provided with a notch, which notches engage with the knife edge of F, that on E when F falls by the action of the spring K and solenoid H, and that on D when F rises.

With the voltage across the solenoid equal to the desired normal

value, the lever G is horizontal, and F clears both D and E. If the voltage rises F falls, and when E in its to-and-fro motion comes up to it, the pawl C is released and, engaging with the toothed wheel A, turns it in a clockwise direction regulating the booster field by means of R, so that a charging booster voltage is obtained. At the same time, the engaging of Q and S lowers the dashpot end of P, pulls down the flat spring M, and releases the tension in L, enabling the spring K to tend to prevent the raising of the solenoid core and consequent lowering of F from giving over-regulation by tending to bring F back to its mean or neutral position.

The oil in the dashpot is all this time flowing through the hole in the piston to enable M to return to its normal position, but if, when this happens, and G is once more horizontal, the voltage has not attained its correct value, the action will be repeated, and this goes on until proper regulation has been obtained.

The effect of a fall in voltage is precisely similar to that described, but, of course, in an opposite sense.

The Thury regulator cannot be called quick-acting in the same sense, as, say, the Tirrill regulator, and it can readily be conceived that much trouble might be experienced with it should an attempt be made to make the operation dependent on the variations in generator current instead of line voltage. Some figures regarding its quickness were given by Dr. Morris in the discussion on a paper by Mr. Tilney.* The regulator he referred to operated a booster with cast steel poles, and he stated that the regulator, which worked at the rate of two notches per second, operated at one-third to one-half of the speed of the building up of the booster voltage, but that it could more nearly attain the speed of decrease in booster voltage. It would therefore seem that the field of this regulator is on, say, lighting systems where the peaks are much slower and less violent than those on a traction or industrial power load.

From the diagram it will be seen that the booster is provided with a series coil. This may be made to relieve the regulator of a good deal of the work, as, if designed to give, as nearly as can be obtained, a level compound effect in the battery-booster portion of the circuit, the regulator only requires to perform the function of a prompter, so to speak, and to compensate for the varying state of the battery. This all tends to make the apparatus quicker in action, the checking action of the oil pump tending to prevent overshooting of the regulation.

As a matter of fact, were the regulator made responsive to fluctuations in generator current, and provided with a coil such as that described above, the scheme would be closely akin to the Highfield and other schemes, where control is effected by means responsive to current, for it will be seen that, with the regulator coil H responsive to generator current, and a series coil responsive to battery current, the overall effect is responsive to the total current increase.

A point to be noticed in connection with the regulator, and one

* *Journal of the Institution of Electrical Engineers*, vol. 36, p. 605, 1906.

which would badly affect its operation, if connected so as to be responsive to generator current and used on a highly fluctuating load, is that the back control is not responsive to any of the factors governed by the action of the regulator. It is purely mechanical, and it is questionable whether a mechanical arrangement can be adjusted to give satisfactory results under the variable and severe conditions prevailing in ordinary battery and booster work.

Systems of Lincoln and Bijur.—Other systems which may be mentioned are those due to Lincoln and Bijur, which act on a principle similar to that of Entz. In both cases a controlling field is connected between the middle point of a number of cells and the junction of two resistances connected across those cells. In Lincoln's scheme, which is patented in connection with alternating-current systems, the torque of a small alternating-current motor, which is responsive to variations in main generator current, is balanced by a spring at the desired value

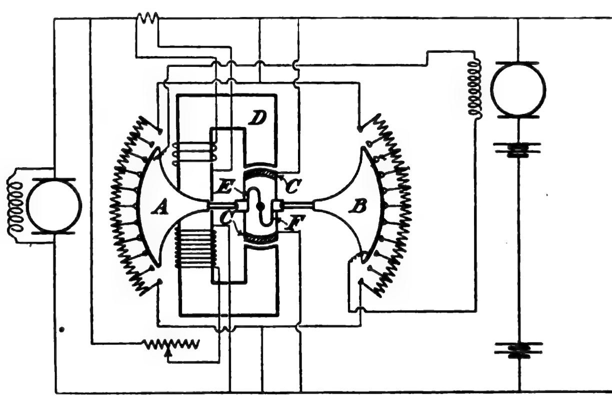


FIG. 16.—Brown-Boveri Booster.

of the current. An increase or decrease of generator current causes a rotation of the motor, and hence, by means of ordinary switches, a variation in the relative values of the two resistances connected across the cells, the controlling field being therefore energised in an appropriate direction.

In Bijur's system a solenoid is used, the pull on the core, which is due to generator current, being balanced by a spring. Variation of the two regulator resistances is accomplished by means of contact points dipping into mercury cups.

In neither of those regulators is there any provision made for a back-checking action, and variation of the resistances could not conveniently be made so quick and yet so gradual as in the case of the Entz regulator.

Brown-Boveri Booster.—The Brown-Boveri voltage regulator is applied as shown in outline in Fig. 16. Two resistances, each provided with a

large number of contacts, are connected in Wheatstone Bridge fashion, the booster field taking the place of the galvanometer. The terminals of the field are connected to two contact sectors A and B, which are fixed to a moving coil system. The moving coil C moves in the gap of a differentially wound magnet D, and carries an approximately constant current: absolute constancy of current is not indispensable. There is no spring or other control to bring the moving coil into any recognised mean position, but it can come to rest in any position which results in a balancing of the magnetic effects of the differential coils on D.

One of the differential windings is connected across the line voltage or a part of it, and the other carries a portion of the generator current to be regulated, the working of the scheme being as follows:—

The differential coils may be assumed to be balanced initially, with the sectors A and B in the mid-position shown in Fig. 16, the line load being equal to the desired normal value, which the generator should take, and the battery in a floating condition. The booster field will then have no current flowing in it.

An increase or decrease of line current will cause a corresponding alteration in generator current, which will upset the balance between the magnetic effects of the differential windings, and cause the moving coil and the contact sectors to rotate in such a direction as to give the necessary discharge or charge booster voltage.

Adjustment of main generator current is effected by adjustment of the strength of the shunt winding on the magnet.

It is claimed that over-regulation is prevented by the lightness of construction of the moving parts of the regulator, and the provision of a special adjustable damping arrangement. The latter consists of a toothed sector, which is coupled by a flat spiral spring to the spindle of the moving system; this sector drives a pinion on a disc which moves in the field of a permanent magnet. The flat spring referred to constitutes a flexible coupling link between the moving contact sectors and the damping sector, and therefore the former can move relatively to the damping system, the tension in the spring depending on the relative positions of the sectors.

A variation of generator current causes the contact sectors to move through a distance in excess of that required for regulating purposes. This puts a higher voltage across the booster field than that actually required, and enables it to build up its magnetism quickly in the manner explained earlier in the paper. The movement of the contact sectors tightens the spring coupling referred to above, and the damping sector begins to move, the returning of the generator current towards its normal value and the tension in the spring coupling bringing the contact sectors back before over-regulation of the generator current can take place, but, owing to the damping sector having moved into a more advanced position, not far enough to overshoot the initial position in the opposite direction and thus cause hunting.

The springs E and F maintain the pressure between the contact sectors and the resistance contacts, and the pivoting of the sectors

in coned cups as indicated in the figure gives a rolling and practically frictionless contact between sectors and contacts, the latter being arranged on an arc, the radius of which is somewhat greater than that of the face of the sectors.

It may be noted that the initial increment of generator current required to operate the regulator is not required to keep the contact sectors in their proper position, because—there being, as already mentioned, no spring control—the sectors become stationary in the position which brings the generator current back to the value at which the effects of the two windings on the differential magnet exactly neutralise each other.

This regulator possesses the defect of all differential systems in that compounding of the main generator will affect its working. Quick operation with an absence of over-regulation is claimed, but, since the action preventing over-shooting is not responsive to any of the factors governing the battery charge and discharge, it is difficult to see that the action can be made thoroughly effective. In this it resembles the Thury regulator, the checking action being purely mechanical.

Methods of Using Boosters.—The ways in which a battery-booster plant can be used are many and varied. Booster sets may be 2-wire or 3-wire, although the latter are not so satisfactory as the former. In 3-wire systems it is quite common practice now to run the battery and booster across the outers of the system like a 2-wire set. A 3-wire set consists merely of 2 sets with a common point at the middle wire of the system. The outline of such a scheme is shown in Fig. 17 for a Highfield booster. The booster on the positive side endeavours to keep a constant current coming from the generator positive lead, the value depending on the setting of the exciter voltage. That on the negative side endeavours to keep a constant current in the negative dynamo lead, the value of this depending on the adjustment of the corresponding exciter. Obviously things get somewhat mixed if the two exciters are not adjusted alike, as the currents in positive and negative dynamo leads must be the same. For satisfactory working the exciter field regulators have to be interlocked, but even this presupposes an accuracy in design not always obtained in practice. The foregoing remarks, although illustrated by reference to a Highfield set, are not confined to this type of booster.

Exceedingly good results are obtained by the use of the battery and booster directly connected across the outers of the 3-wire system in conjunction with a separate balancer, and, with this arrangement, loads of a very highly fluctuating nature can safely be connected across the outers of supply without the busbar voltage being affected. For example, in one station shunt-wound generators are run directly across the outers in parallel with a battery and automatic reversible booster, and a rolling mill motor load is supplied from the same bars as public and general lighting without any adverse effect on the voltage. Also, in the *Electrical Review*,* plant was described which is in opera-

* *Electrical Review*, vol. 67, p. 59, 1910.

tion at Blackburn Corporation Electricity Works, and which makes provision for the town traction to be supplied from the outers of the 3-wire lighting and general supply system through a motor-generator. A battery and booster operate in parallel with the generator side of the set, and equalise the load so that the variations are not noticed on the 3-wire system. The generator current is held steady within about 20 amperes from the mean, which is normally 600 to 800 amperes.

Arrangements such as have just been mentioned are often capable of showing large economies, but before an engineer definitely decides to supply such highly fluctuating loads from his lighting busbars, he should satisfy himself thoroughly that the equalising system he chooses

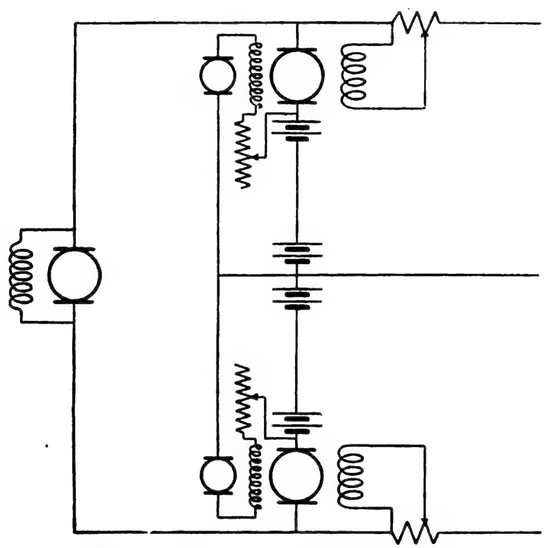


FIG. 17.—Three-wire Highfield Booster.

is capable of giving the results he wants, and the best way to make sure of this is to see a similar plant in satisfactory operation. He should experience little difficulty in this direction, as firms who exploit satisfactory systems are invariably pleased to demonstrate the advantages accruing therefrom. The best system should be installed : it is usually but poor economy to put down a second-rate plant for the sake of saving a little in capital expenditure, and have only second-rate results, and probably much worry, during the whole life of the plant.

Balancing on a 3-wire system where a 2-wire battery and booster are used, instead of being obtained by means of a separate rotary set, may be effected on the armature of the booster motor by means of a choking coil in the middle wire of the system connected to slip-rings on the armature. This, of course, means that the motor armature has

to be larger than would otherwise be the case, the increase in size depending on the magnitude of the out-of-balance current. As an alternative to this the booster may be balancer-driven, in which case the balancer machines require to be made larger than is necessary to deal with the out-of-balance current, the increase in size being dependent on the power required to drive the booster.

Of course, in all those cases a middle-wire connection should be provided for the battery, and, at times of light load or in emergency, balancing can be done by means of the battery. This means unequal discharging of the two halves of the battery, but special change-over arrangements can be made to overcome this difficulty. There is usually little difficulty in providing arrangements for dealing with any problem arising in practice, but it will probably be generally conceded in this connection that it is a wise plan to have the whole of the plant from one firm, particularly in cases where the battery is on maintenance, as is common nowadays; otherwise there may be conflicting opinions as to the effect of the treatment to which the battery is subjected by the working of the booster.

Batteries and Boosters for Winding Plant.—Colliery winding and similar work provides an opening for battery-booster plant of an instantly reversible character, provided the initial cost can be kept down. Flywheel sets are often employed, but the large reserve of power in a battery would be a distinct advantage in many cases. There is no necessity to limit the use of this type of winding plant to direct-current systems, as it can be equally well applied to systems in which the supply takes the form of alternating current. The system is, of course, in competition with flywheel equalisers on both alternating-current and direct-current systems, but a flywheel, although it decreases the peak power drawn from a supply, cannot flatten out the demand in the way a sensitive battery-booster plant can, and, where power is taken from a supply company and paid for on the basis of maximum demand, this is a point worthy of serious consideration.

The method of using battery-booster plant on alternating-current systems is discussed later on in the paper.

In the *Electrician*,* Mr. G. Hooghwinkel refers to electric winding on direct-current systems, use being made of batteries and boosters; he considers that more attention should be given to this method than has hitherto been bestowed on it. Objection is raised to it on the score of cost, and certainly the method is at present somewhat expensive. The advocates of the system, however, do not claim that it is as cheap as others, but that the advantages of increased storage capacity and greater equalising capabilities of the working plant amply justify the extra expenditure in many cases.

Dr. Rosenberg † refers to the use of a special machine with a storage battery connected across its terminals to replace the flywheel

* *Electrician*, vol. 67, p. 85, 1911.
† *Journal of the Institution of Electrical Engineers*, vol. 46, p. 434, 1911.

in electric winding and hoisting engines without, however, giving any detailed explanation of such a scheme.

Crompton's Winding Scheme.—Fig. 18 shows an arrangement proposed by Crompton & Co. for employment in equalising on a colliery winding load.

The operation in outline is as follows :—

The booster generator Y is, to begin with, put in opposition to the line voltage by means of its field-regulating and reversing switch, and the armatures of the winding motors M M are thus connected across a low voltage giving a slow speed. Those motors are provided with one set of field coils connected permanently across the line voltage, and another set connected between one line and the junction of the armatures.

When the motors are switched in it will be seen that the latter set of coils is excited from the line voltage, but as the motors speed up the exciting voltage is decreased, being reduced by the voltage across the second armature. The effect of this is to give a strong field, and there-

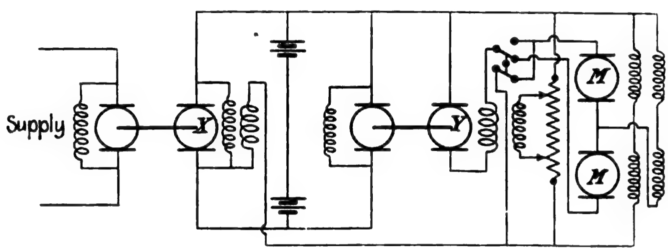


FIG. 18.—Crompton's Winding Scheme.

fore a large torque, at starting, gradually decreasing as the winding motors speed up. The field of Y may now be decreased, and finally reversed to increase the speed of the motors to a maximum. The effect of the series coil of the machine Y is to limit the speed of the winding motors, the coil being connected so as to act against the shunt coil of Y when the voltage of Y is added to the line voltage, and so reduce the voltage applied to the winding motors and increase the field due to the second set of coils. The series field of the generator X takes the place of a diverter battery booster. It acts in opposition to the shunt coil of X, and an excessive demand for current accordingly reduces the voltage of X and allows the battery to come to the assistance of the machine. The direction of rotation of the winding motors is reversed by means of a switch in the armature circuit.

In order that braking of the winding motors may be obtained with a regenerative effect the shunt field of Y is reversed, so that the voltage of Y again acts against the line voltage, being added to the back E.M.F. of the motors. The series field of Y will, with the regenerative current, again act in opposition to the shunt field, and, by limiting the field of

Y, and therefore its voltage, will limit the regenerative braking current supplied to the line by the winding motors.

The author is not aware whether the foregoing scheme has been put to actual use, but from the method employed to make the battery work it is fairly obvious that, so far as equalisation is concerned, the results will not be of a very high order of excellence. This being recognised, it should be possible to keep down the initial cost, as, seeing that there is no very efficient means of making the battery work,

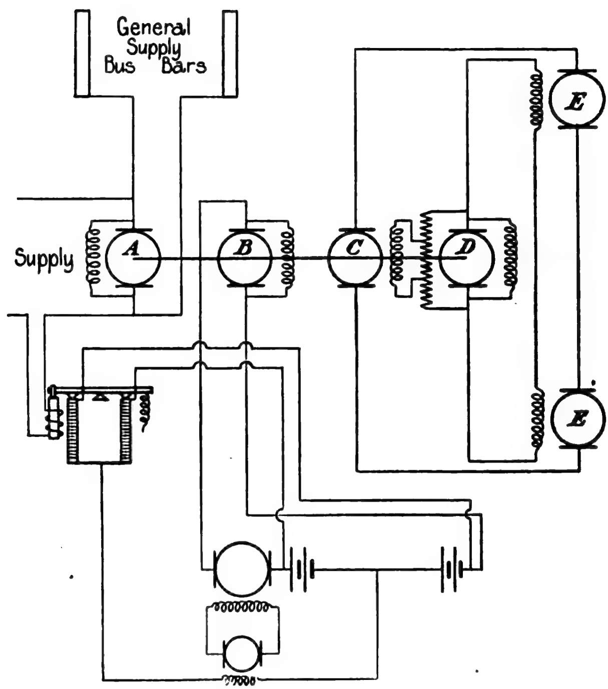


FIG. 19.—Battery and Booster for Winding Motors and General Supply.

there will be little use in installing one of large capacity. The good features in the system may be readily obtained in other ways, which can be applied to schemes which render it possible to obtain better load equalisation.

Entz Booster for Winding Plant.—Fig. 19 shows one way in which an Entz or other externally regulated booster can be employed, the Entz being shown for simplicity. The equalising machinery comprises a motor A, a machine B, which can act as either motor or generator, a reversible-voltage generator C and an exciter D, which is only necessary if no other source of excitation is available. The winding motors

are shown at E E. A battery and booster are connected across B. Equalisation is obtained in the scheme shown in the Fig. on the whole of the system, the carbon regulator being responsive to small variations in the total power taken from the supply.

The winding motors E E are excited by machine D, and their direction of rotation and speed are controlled by a reversing and regulating switch in the field of C. If equalisation is only desired in the winding load, the general supply can be drawn from the main supply to the left of the Entz solenoid. This method is illustrated in Fig. 20, which only shows a portion of the scheme, and in which the

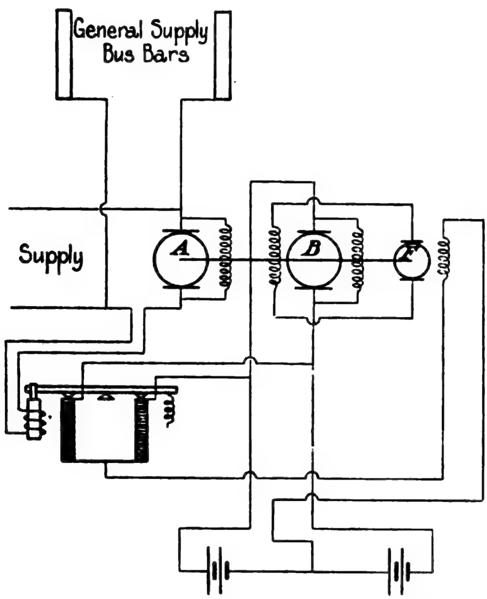


FIG. 20.—Entz Control of Winding Plant.

battery booster is replaced by an auxiliary field on B, connected to an exciter F excited from the carbon regulator. The winding motors may be excited from the battery.

The working of the Entz regulator has already been described, and a detailed description of the working of the schemes shown in Figs. 19 and 20 is hardly necessary.

The same general scheme of regulation could be applied to plant taking its supply from an alternating-current supply scheme, suitable auxiliary apparatus being provided of the type described later.

The foregoing may be taken as typical of the methods of equalisation proposed in connection with batteries and boosters employed on this kind of work.

Regulation on Alternating-current Systems.

It has been already pointed out that a booster employed in conjunction with an external automatic regulator has an advantage over the diverter booster in that much quicker reversal of voltage can be effected, due to the fact that the regulator can be so designed that a multiple exciting effect is obtained, the automatic action of the regulator checking the effect before over-regulation takes place. Another advantage is that with a good external automatic regulator the benefits of accumulator storage can be readily obtained on alternating-current systems, the main solenoids of Entz and Tirrill regulators, for example, being easily adapted so as to be suitable for alternating-current working. Very little has been done in this direction in this country, due, perhaps, to a large extent to our proverbial conservativeness, but very large installations have been put down in America operating on this principle. Various papers have been read before the American Institution of Electrical Engineers describing both complete installations and pieces of auxiliary plant for controlling the batteries. The most prominent name in this connection is that of Woodbridge, who has invented many exceedingly interesting pieces of apparatus, most of which are in use at the present time, and some of which will now be described.

The use of diverter boosters, as described in the earlier part of the paper, is confined to direct-current systems, and regulation of alternating loads must be effected by plant controlled by an external regulator, although a special exciter described hereafter is worked on a somewhat analogous principle to that of the direct-current diverter booster. Regulation may be required on purely alternating-current systems, or on systems on which both alternating and direct current are employed; different arrangements have naturally to be made to suit the different cases. Arrangements have to be provided for transmitting power both from the alternating-current side of the system to the battery, or direct-current side, and for transmission in the opposite direction. The external regulator or exciter is used for controlling the transmitting link between alternating-current and direct-current sides of the system.

Alternating-current Solenoid.—As in the case of the direct-current booster, perhaps the simplest arrangement is the employment of an Entz regulator operated by an alternating-current solenoid, responsive to variations in the energy component of the alternating current, the regulator controlling the alternating-current/direct-current transmitting plant. Such a solenoid is shown at F in Fig. 21.

It consists of an iron magnetic circuit magnetised from the line potential difference on the alternating-current circuit, the magnetising coil being shown wound round the middle yoke. On the enlarged end of this middle yoke there is placed a movable coil, which is suspended from one end of the lever of an Entz carbon regulator; the coil is connected across the secondary of a current transformer, the primary

of which is in series with the main which has no voltage connection. The flux in the core splits and crosses two air-gaps to re-enter the centre core, and, being produced by the potential coil, connected as shown, will lag 90° in phase behind the line voltage. At unity power factor in the main alternating-current circuit the current in the movable coil will lag 90° in phase behind the voltage across the potential coil, and hence the current in the movable solenoid and the flux in the air-gaps will be in phase with each other, and a pull will be exerted by the solenoid on the lever of the regulator, the pull being proportional to the product of the flux in the air-gaps and the current in the solenoid. If the power factor is not unity the pull of the solenoid will be proportional to the product of the magnetic flux in the air-gaps and the energy component of the current, this

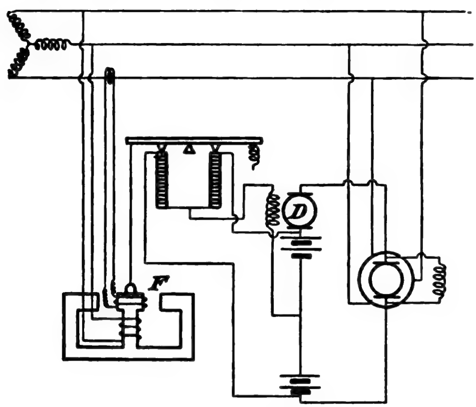


FIG. 21.—Regulation on Alternating-current System by Watt Solenoid and Direct-current Booster.

component being, of course, in phase with the flux. The wattless component of the main alternating-current current will have no effect on the lever of the regulator. The effect of the pull on the lever will be to operate the Entz regulator in the usual manner. An increase in alternating-current energy above the desired mean will cause the booster D to discharge the battery into the rotary circuit. If the energy in the main alternating-current circuit falls below the desired mean (this mean being obtained by adjustment of the regulator spring, as usual) the booster voltage will be in the charge direction, and energy will be transmitted from the main alternating-current circuit *viâ* the rotary converter into the battery. Other types of external regulator may be used in a manner similar to that just described.

Motor-generators and Converters.—Either the motor-generator or the converter type of plant may be used for the transference of power, but the latter is more suitable where quick regulation is

required, as the single converter machine will respond to the control somewhat more quickly than will the combination forming the motor-generator. The boosting effect necessary to cause a transference of energy between the battery and the load circuit may be obtained by the provision of a direct-current booster on the battery side of the transmitting plant, as indicated in Fig. 21, or an alternating-current booster on the load side, as in Fig. 22, which shows both an alternating-current and a direct-current load being regulated, the fields of the boosters being made responsive to small variations in the load on the alternating-current and direct-current generating plant respectively. Details of the method of control are omitted for clear-

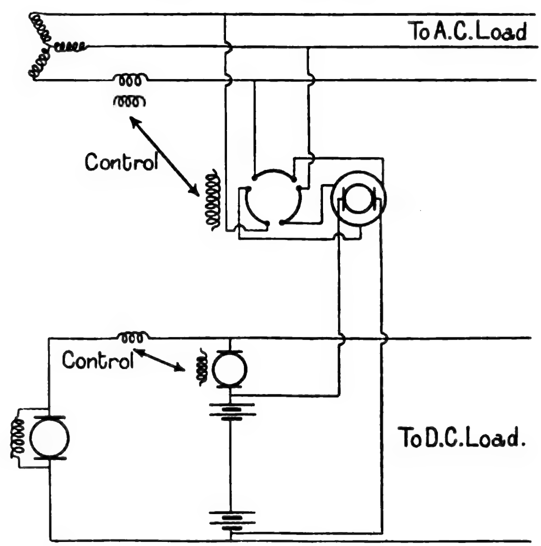


FIG. 22.—Combined Alternating- and Direct-current Regulation. Alternating-current Booster employed.

ness. The use of a booster as indicated should prove very convenient in cases where the booster may be fixed on an existing converter.

Split-pole Converter.—In order that the auxiliary booster plant might be dispensed with the split-pole rotary converter was developed. This machine and its theory are explained in a paper by Mr. J. L. Woodbridge, read at the twenty-fifth annual convention of the American Institute of Electrical Engineers in 1908, and of which an abstract appeared in *Electrical Engineering.** In the ordinary converter there is, of course, a fixed ratio between alternating-current and direct-current voltages, and the object of the split-pole machine is to allow of a variable ratio by causing the direct-current voltage to vary in

* *Transactions of the American Institute of Electrical Engineers*, vol. 27, p. 987, 1908; *Electrical Engineering*, vol. 4, p. 731, 1908.

response to load variations in the generating plant, while the alternating-current voltage is maintained constant, or approximately so.

Fig. 23 is a copy of a figure in Mr. Woodbridge's paper, and serves to show, in an elementary fashion, how the variable voltage ratio is obtained. In the case illustrated the poles are divided into three parts, and the flux distribution is shown roughly at *a, b, c, d, e, f,* under a pair of poles, the flux from each pole being assumed to cover exactly a pole-pitch. Should the excitation be altered so that the two outer parts of each pole are strengthened and the middle part weakened, the result is equivalent to the effect of such a field as that shown at *g, h, i, j, k, l,* super-imposed on the main field. The flux represented by the shaded area Y at *h* is exactly cancelled by an area X, and an area Z shown at *g* and *i*. The result is that the potential of the points P and Q remains unaffected, but the potential of points A and D increases, due to the overall increase in flux between the two points. It will be seen that the points P and Q

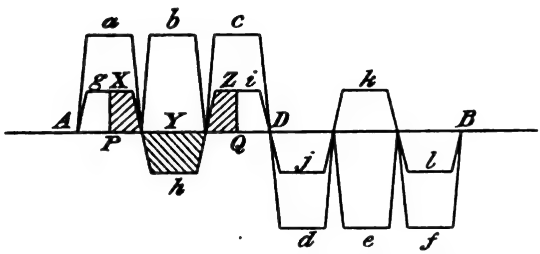


FIG. 23.—Approximate Flux Distribution in Split-pole Converter.

are 120° apart and correspond to 3-phase tappings, and points A and D are 180° apart and correspond to direct current-brushes.

The effect is therefore an increase in direct current voltage without alteration of the alternating-current voltage. An exactly opposite effect on the direct-current voltage would be obtained from a strengthening of the middle part of the pole and a weakening of the outer parts.

In practice there is a neutral zone at the points where the direct-current brushes are placed, but it is found that this, although altering the wave shape of the voltage curve, does not appreciably affect the working of the machine.

The raising and lowering of the direct-current voltage can be utilised to cause a battery connected across the direct-current terminals of the rotary to charge and discharge, alteration of the converter field being made responsive to small variations in the generator load by means of an automatic regulator.

The split-pole converter has also been used as a two-part pole machine with success, and it is found that with a 20 per cent. variation of direct-current voltage above and below the mean—*i.e.*, 20 per cent. on

each side—the variation in alternating-current voltage is about 1 per cent. on each side of the mean value. Plant of this type is in very successful operation in the Gary works of the Indiana Steel Company.

Automatic Exciter for Alternating-current Working.—Mr. Woodbridge, in the paper already referred to, describes a new form of automatic exciter suitable for controlling equalising plant on alternating-current systems. The principle of this is shown in Fig. 24. The figure shows a 2-pole armature revolving in a 4-pole field, the two upper poles being wound so as to have one polarity, and the two lower ones the opposite. The armature windings are connected to the secondaries of current transformers in the main generator circuit, as indicated in the diagram. A revolving field is accordingly set up due to the alternating current in

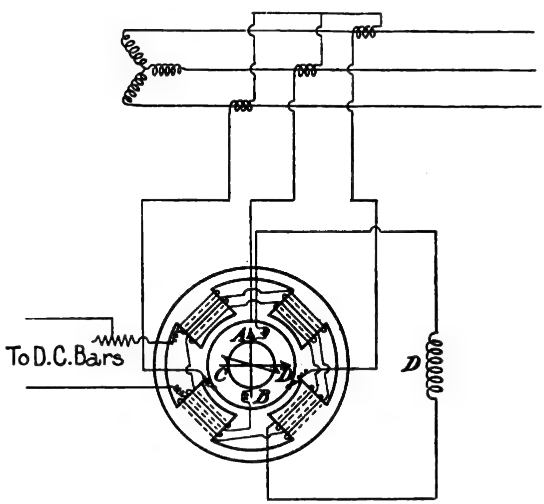


FIG. 24.—Automatic Exciter for Alternating-current Working.

the armature. This field is rendered stationary in space by the armature being revolved synchronously in an opposite direction by means of a synchronous motor directly coupled to it.

The field winding is connected across a constant potential direct-current supply, and the current in it can be so adjusted as to just balance the field set up by a desired value of alternating current.

There are two pairs of brushes on the commutator, one pair being fixed so that the diameter joining them is in the direction of the field set up by the alternating current, and the other pair displaced at 90° from the first pair. This second pair are short-circuited, and the first pair are connected to the controlling field of the equalising plant.

When the field produced by the alternating current is just neutralised by the magnet winding there is no potential difference between the

points C and D, but, should the two opposing fields not balance each other, there will be a resultant flux in the direction of the vertical centre line, and hence there will be a voltage between the short-circuited brushes. A current will therefore flow between those brushes, setting up a flux in the direction of the diameter joining them. This flux will cause an E.M.F. to be generated between the other pair of brushes A, B, which are connected to the exciter field shown at D, the booster or other equalising machine being, as a consequence, excited in such a way as to prevent further variation of the main generator load than the small amount necessary to upset the balance of magnetomotive forces and give the effect just described. The second winding shown on the magnets is designed to compensate for armature reaction in the exciter due to the current flowing to excite the controlling field D.

Advantages of Automatic Exciter.—The following are the important features claimed in connection with this exciter.

1. It acts as a multiplying device, a magnifying effect being obtained by the short-circuit current flowing between brushes C and D. This makes it sensitive to small changes in alternating-current load.
2. By the provision of a suitable angular relation between the exciter armature and the armature of the synchronous motor which drives it, the exciter can be made to respond to any desired phase component of the alternating current to be controlled.
3. It may be used to control the power factor of the main circuit if the connections to the pairs of brushes are interchanged, the exciter field winding being replaced by a field coil on some synchronous machine connected to the supply. Two exciters such as that described can be used, one being employed to regulate the load on the main generating plant, and the other to regulate the power factor of the circuit in the manner just indicated.

Another advantage claimed for this type of exciter is that the automatic regulation of load can be stopped immediately by the short-circuiting of the current transformers, armature reaction preventing excessive currents even with considerable direct-current excitation. This is of considerable advantage as, once the apparatus has been used for a short time, the regulating rheostat in the separately excited shunt field circuit can be calibrated in terms of the alternating-current generator current, so that when it is desired to put the battery into service as a regulator of the load it is only necessary to set this rheostat to a position corresponding to the load desired on the generating plant, and open the switch short-circuiting the secondaries of the current transformers. The generator current will immediately assume the value imposed on it by the value of the exciter shunt winding.

Plant at Gary Steel Works.—A short description of the plant installed at the Gary works of the Indiana Steel Company, where the foregoing

apparatus is in actual use, may be interesting. There are eight blast furnaces, and the gas from those is practically all employed in a useful manner. Part of it is utilised to drive the generating plant consisting of fifteen gas-driven 2,000-k.w. alternating-current sets, and two direct-current sets of the same output; there are, in addition, two 2,000-k.w. steam turbine-driven alternating-current sets.

The rolls of the rail mill, which has a capacity of 2,000 tons of finished rails per 24 hours, are driven by five induction motors aggregating 22,000 H.P. comprising three units of 6,000 H.P. and two units of

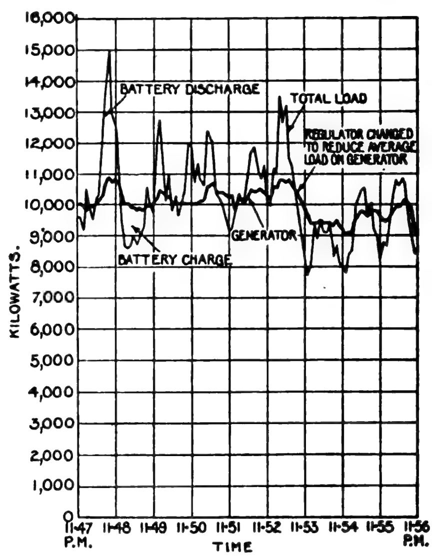


FIG. 25.—Showing Equalisation obtained on Alternating-current System.

2,000 H.P. Those few particulars give an idea of the magnitude of the installation.

It has been found necessary, although the large motors have been provided with equalising flywheels, to install a storage battery to take care of the load fluctuations on both alternating-current and direct-current parts of the system. The battery consists of two sets of 125 cells, each set capable of giving 4,320 amperes for 1 hour and 8,640 amperes on the peak for regulating purposes. Regulation on the alternating-current load is effected by means of split-pole converters and Woodbridge's special exciters, and on the direct-current load, by means of boosters controlled by Entz regulators, all of which have already been described.

One of the most valuable results obtained by the use of the battery equalising plant is the increased speed and output of the rail mill, a

very decided reduction in output being the result of a disconnection of the battery.

Fig. 25 gives some idea of the equalising effect obtained on the alternating-current side of the system. The generator load was obtained from a wattmeter suitably connected and is represented by the heavy line. The light line was plotted by the addition of the battery output and input read at intervals of 5 seconds.

It may be mentioned that the patent rights for all the apparatus described are held by firms in this country, and that its use need not be confined to America if there are openings here.

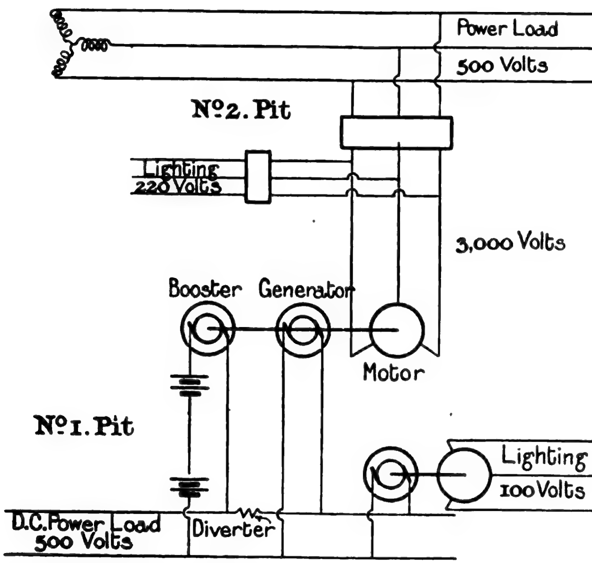


FIG. 26.—Alternating- and Direct-current Plant at Hucknall Collieries.

Alternating-current Colliery Plant.—There is installed at the Collieries, Hucknall Torkard, Nottinghamshire, an alternating-current/direct-current plant, including a battery-booster equipment; but this differs from that just described in that the booster is of the Lancashire diverter type, and only equalises on the direct-current load. The scheme of connections is shown in outline in Fig. 26. Surplus power available at No. 2 pit is used to drive a motor-generator set, the machines composing which are alternating-current motor, direct-current generator, and battery booster.

The power load at No. 2 pit is alternating current, and that at No. 1 pit is direct current, whilst the lighting at both pits is alternating current. The action of the booster is to tend to preserve a constant load on the direct-current generator of the motor-generator set, and thus a constant output from No. 2 pit to No. 1 pit.

The direct-current generator current being set to a suitable value, the battery may be left in a high state of charge at suitable times, and used to supply all the power load at No. 1 pit, and, by means of suitable arrangements, the lighting load at both pits. An account of the plant appears in a paper read by Mr. William Maurice before the Institution of Mining Engineers in June, 1910.*

In this installation the advantages of accumulator storage have been recognised, and are made use of in the working of the system, but better equalisation of load could easily have been obtained by the provision of such a scheme as is indicated in Fig. 22.

Practical Results.

Pirani Booster.—The following figures, Table I., are taken from the *Engineer* for April 14, 1911,† and give the results obtained from a Pirani booster, the readings being taken over a period of half an hour.

Table I.

	1st Test.	2nd Test.	3rd Test.
Maximum line amperes	4,500	3,210	3,600
Mean line amperes	2,875	1,650	2,150
Minimum line amperes	1,110	475	700
Maximum generator amperes ...	3,600	2,050	2,600
Mean generator amperes ...	2,700	1,625	2,075
Minimum generator amperes ...	2,125	1,100	1,325
Maximum busbar voltage ...	765	767	765
Mean busbar voltage	750	750	750
Minimum busbar voltage ...	738	738	740

It will be noted that the variations in generator current are respectively 1,475 amperes, 950 amperes, and 1,275 amperes from minimum to maximum, and the corresponding variations in busbar voltage are respectively 27 volts, 29 volts, and 25 volts. Those figures indicate anything but perfect regulation, and are poor in comparison with results obtained with other boosters.

Entz Booster.—The figures given in Table II. were obtained from a test made in a works where a battery and an Entz booster were used to equalise on the total load. The first part of the test was made with one generator working during the day, and two at night when the lighting load came on, and the second part with the battery-booster plant and one engine only in use over the whole period. Some time after the tests were carried out extensions were made which would

* *Iron and Coal Trades Review*, vol. 80, p. 879, 1910.
† *Engineer*, vol. 111, p. 375, 1911.

have necessitated the running of two engines day and night, and, had a test been made then, the saving due to the equalising plant would have been even more marked. The load was of an exceedingly highly fluctuating nature, worse even than a traction load, and, taking into account the reduction in wear and tear of the generating plant, in addition to the coal saving, a very few years will be necessary for the battery and booster plant entirely to repay the capital initially put out on it.

It will be observed that, as the second generator was only required for about one-third of the running time of the first part of the test, the conditions of load were not the most favourable to show the maximum economy made possible by the battery and booster plant. The generator which ran through the whole of the first part of the test was the one used with the booster. The engines were of the high-speed non-condensing type.

TABLE II.

Running Plant.	Duration of Test.	Total Units.	Average Kilowatts.	Steam per Hour.	Steam per Kilowatt-hour.
	Hours			Lbs.	Lbs.
Two generators ...	138	8,536	61·85	3,735	60·43
One generator with battery and booster	136	8,330	61·25	2,649	43·25

One generator ran 48 hours and one the whole 138 hours.

From the above the saving in steam per kilowatt-hour is 17·18 lbs. or 28·4 per cent.

In the *Electrical Review* * it is stated that at Greenock Corporation Electricity Works, where the traction load was about $\frac{3}{8}$ of the total load on the station, the installation of an Entz booster and battery reduced the coal per unit generated from $6\frac{1}{4}$ lbs. to 5 lbs.—that is, made a 20 per cent. saving in the total coal bill. It was estimated that the plant would pay for itself in from 3 to 4 years.

In another traction station, where the generating plant consists of Diesel oil engine sets, the installation of a Lancashire booster and a battery made a reduction of 18 per cent. in fuel consumption.

SUMMARY OF CONCLUSIONS.

In a brief review of the paper, it may be observed to begin with that in the installation of a battery and booster on a highly fluctuating load, both the generator and battery are operated under satisfactory conditions, for it is a fact that batteries working under such circumstances

* *Electrical Review*, vol. 59, p. 179, 1906.

usually remain in very good order indeed. For example, the battery at Greenock already referred to was not on maintenance, and was in use for six years before any money was spent on it, and then it only required cleaning out.

With regard to the boosters there can be little difference between the actual practical results obtained from the use of those of Class (B) and the Lancashire booster in Class (A). The other members of Class (A) described in the paper certainly cannot be so satisfactory as those referred to. Of course, there are the difficulties introduced by the running of compound generators and the effect of a high state of battery charge, but those can to some extent be avoided. If the booster gives fairly satisfactory results the compounding of the generator can be reduced, and there is usually little occasion to run the generator at such a current and for such a time as to give the effect shown on the chart in Fig. 8 due to the high state of charge of the battery.

The fact remains, however, that boosters of Classes (A) and (B) must be more sluggish in action than those of Class (C), certainly more so than those of this class in which an overshooting effect, suitably checked, can be arranged for, even although an additional link is introduced into the system in the form of an exciter. The exciter in boosters of Class (B) do not, of course, enter into the question, as their fields are not reversed during working. Where considerations of field copper are the cause of an exciter being used with a Class (A) booster the sluggishness becomes still more pronounced.

The main factor causing the lag in diverter boosters is, as already pointed out, the use of the diverter itself. When a variation, say an increase, in line current occurs, the first increment must perforce come from the generator, and the diverter being non-inductive this increment may be, and usually is, very considerable, since, as has been shown, there is a great difference between the initial rate of rise of current in the diverter and that in the diverter coil in parallel with it. It is obvious, too, that, right through the entire action, the booster voltage is dependent on a previous variation in line current, and the above-mentioned effect has continually to be reckoned with. This will help to make it clear why lamination of the entire field system of such boosters is considered by many to be absolutely essential.

There can be but little doubt, therefore, that externally regulated boosters are quicker in action than those of the other classes, even without the refinement of laminated fields, and with the addition of an exciter. The curves shown in Fig. 27, for example, were obtained by the use of a booster and exciter provided with standard laminated poles, and standard solid cast-iron field frames. A comparison between the various generator current charts and figures will be interesting in this connection.*

With regard to the respective merits of the boosters in class C, but little can be said as far as regulation obtained is concerned, the

* Fig. 28 shows the chart illustrating Mr. Turnbull's paper of 1906 already referred to on page 300

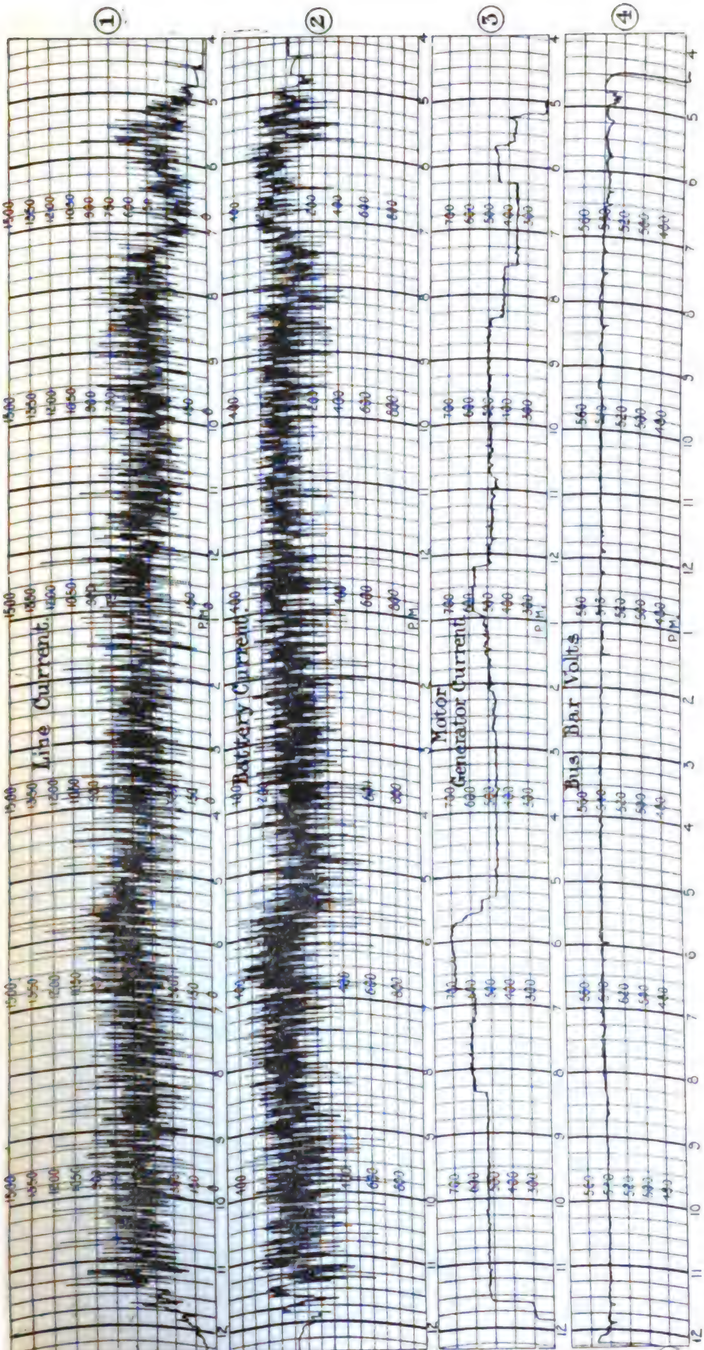

Line Current.
Battery Current.
Motor Generator Current.
Bus Bar Volts.

FIG. 27.

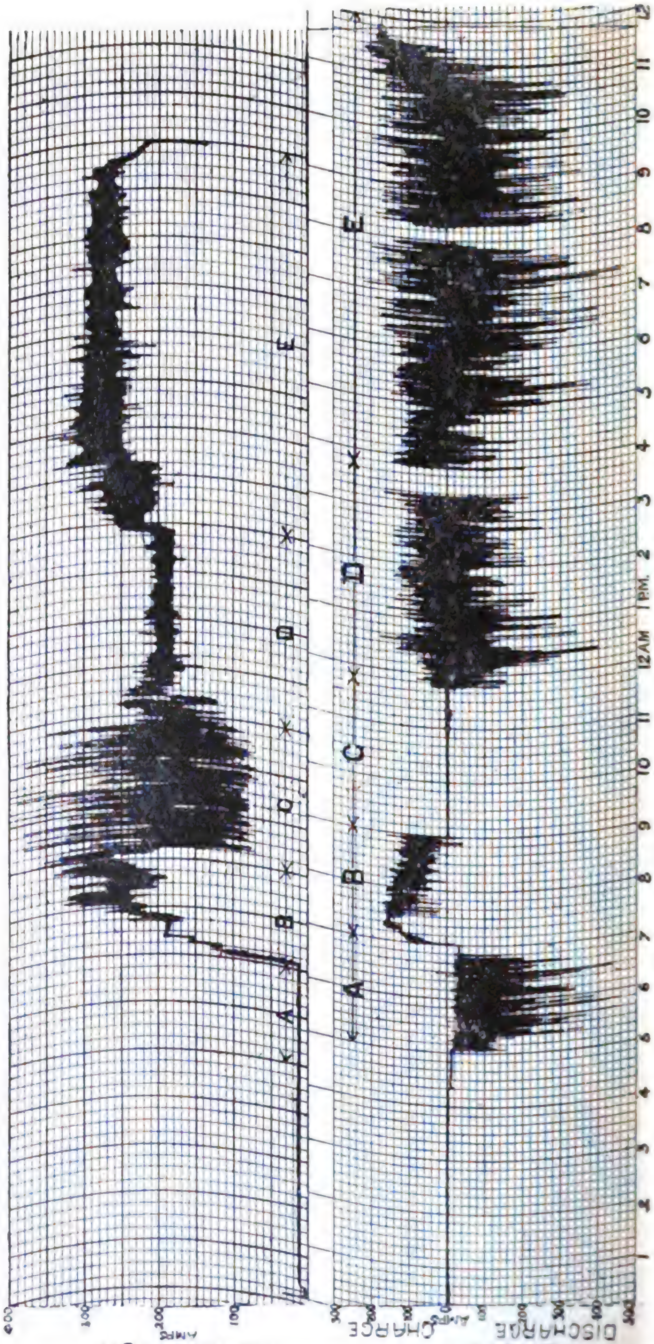

GENERATOR
AMPS
BATTERY
CHARGE
DISCHARGE
AMPS
A
B
C
D
E
12 AM
1 P.M.

FIG. 28.

Entz booster being the only one which has been used to any extent in this country. It will be seen that it possesses the great advantage of extreme simplicity and the other equally important advantage that it employs absolutely no moving electrical contacts, and those are points which, coupled with the fact that it produces such generator charts as those shown in Fig. 27, provide a strong argument in its favour.

DISCUSSION.

Mr. J. S. HIGHFIELD: The author refers at the beginning of the paper to the general use of batteries, and amongst other things to the fact that to-day lead storage batteries can be provided and maintained at a comparatively low cost. I quite agree that that is a fact. The lead storage battery to-day is an exceedingly good piece of apparatus, provided it is suitable for the output. But I would like to say, before leaving this part of my remarks, that I wish the makers of batteries would devise some method of charging for maintenance that is not on the principle of the present Insurance Bill, that is to say, that the healthy people should pay for the sick ones. I have a great number of batteries under my own charge, and I take immense care of them ; I pay very high sums for their maintenance, and I always feel that I am paying for the people who use their batteries less carefully. With regard to the use of boosters, if the curve of a battery charging and discharging were a straight line, so that the battery took its charge at a few volts above the pressure at which it gave out the discharge, the design of the automatic booster would be a perfectly simple matter, because all that would be necessary would be to deal with the increased volts that are required when the discharge is given, which would be on the assumption proportional to the line current. The difficulty of designing an automatic booster is that the battery curve of charge and discharge, the time and volts curve, is not a straight line, and that, further, the curve turns up very quickly, as every one knows, when the battery comes to its final state of complete charge. To deal with this varying curve it is necessary to employ the various devices that the author has described—the device of the constant-pressure exciter and the various external regulators that he has referred to. My own view is that in designing a booster for practical work it is advisable not to take account of the extreme end of the charge curve. I think that in working a battery, particularly on loads where variations occur, it is essential, and certainly it is economical, to work the battery at a moderate state of charge, and to complete the charge only at the end of the day's run, or at some time when the load diminishes and more attention can be given to the work of charging. I do not think it is necessary to design a booster to keep constant load on the generator when the battery is absolutely fully charged. As a matter of fact, there are very few boosters which will work in that way, and fortunately, as I say, it is not necessary. The automatic booster is required Mr Highfield.

Mr. Highfield. to deal with two classes of loads: loads that vary comparatively slowly, and loads that vary with great rapidity, such as winding loads; and the problem is, which of the two should be employed? For instance, in the Thury regulator, an external regulator, the regulation is perfectly satisfactory as long as the variations in the load are slow, but when the variations become exceedingly rapid then the Thury regulator is not sufficiently quick, and other forms of regulator work in very much the same fashion. In dealing with very rapid variations the author has referred to the fact that the diverter is not altogether satisfactory, and I agree that as usually designed that is the case. The current growing very rapidly in the external circuit flows through the diverter and coils in parallel. The diverter is usually non-inductive, and consequently the current increases in the diverter at a greater rate than it increases in the circuit around the booster fields. What should be done is to make the diverter inductive or to use resistance metal having a positive temperature coefficient. It is a very simple matter to wind the resistance on an iron core, and by that means the growing current in the external circuit is deflected round the fields of the booster. That, I think, would be a satisfactory solution. I say "I think" because I have not used such a diverter in connection with boosters, but I have used it in connection with series-wound generators, and I find that for this purpose it works in a satisfactory way. In dealing with very rapidly varying loads it is most useful to put a heavy flywheel on the booster itself, because the load on the motor driving the booster must vary with great rapidity in order to deal with the extra load that comes upon it. A flywheel makes all the difference between successful working and non-successful working. Laminated fields enable the booster to respond more rapidly to the variations of pressure and of load than boosters with unlaminated fields, and it is clearly impossible when the current changes very rapidly to make the field strength change at the same speed unless they are laminated. But in practice with multipolar machines the ordinary laminated poles are, I think, sufficient. With bipolar machines it is essential to laminate throughout. I think in considering the design of boosters it is very essential that they should be designed so that the connecting up and the adjustment are simple matters. If a station is designed for dealing with fluctuating loads—tramway loads and power loads of various sorts—I am not in agreement with the practice of using compound generators; if it is decided from the first to use a battery and automatic booster in this case the generators should be shunt wound. They are quite able to to deal with the small fluctuations that under these circumstances come upon them; the pressure is quite sufficiently constant, and the use obtained from the battery and booster is very much greater than when the generators are compounded and operating difficulties are less.

Mr. Taylor. Mr. A. M. Taylor: I desire to consider the question rather from the point of view of the central station engineer. I think we want to differentiate quite clearly between "instantaneous" and what I may

call "time" peaks. In the case of time peaks we want perhaps to lop off the peak of a load curve at the central station which occurs for an hour or two at one part of the day, and drop it into a valley on the load curve which occurs at another part of the day. But automatic devices are arranged to deal with successive peaks and valleys following one another exceedingly rapidly, and no doubt an automatic booster is a very valuable arrangement in a case like that. I cannot, however, quite see how the author makes out that there is a saving of 10 to 15 per cent. by adopting an automatic booster where a battery has already been employed without a booster. It is hardly possible to conceive that the individual momentary variations produced even by a traction load, for example, would be anything in the nature of a large percentage of the whole load. It is only when we come to the very large momentary loads, such as are got in alternating-current stations which have heavily loaded motors of several hundred horse-power thrown on, that that occurs. An important question arises, if we are going to use a battery for central station supply, as to whether that battery is going to be tied up to the busbars absolutely for good or for bad, or whether it is going to be cut off automatically at the critical moment when perhaps it is most wanted. As far as I know, in the largest installation in this country directly the load reaches 15,000 amperes the automatic circuit breaker comes in and cuts the battery off from the busbars, not so much, I take it, to save the battery as the boosters. In Birmingham Mr. Chattock is proposing to take the opposite course; we are proposing to tie the battery up to the busbars for good or for bad; and if a sudden unexpected load of 17,000 or 20,000 amperes comes on, as we might have with the regular direct-current load on our system in times of peak load—if everything else went down, as sometimes it has a habit of doing—we want the battery to stand up to the busbars absolutely. We are proposing to introduce a large automatic short-circuiting switch, which is all but closed, so as to get rid of the difficulty of moving the mass of the switch over a long distance. It will only have to close through a very small angle; it will clap the battery on to the busbars and cut out the booster. It would be interesting to know how an automatic booster would behave under this test. The booster has to be protected somehow from being damaged from that short circuit; and to do that we are proposing to design the booster so that it will stand up—in fact we are proposing not to accept the booster until it will stand up—to tests corresponding to short-circuiting the booster, previously wiping out the field of the booster, and cutting off the motive power, so that the short-circuit current is reduced to safe dimensions. It is much cheaper, I think you will find, to design a booster which has got to carry a "short circuit" current for, say, one quarter to half a second, than to design a booster which has to carry the line current, the same current practically for, say, 3 minutes. Then we come to the question of the cost of the booster itself. I think if we are not careful, for central Mr. Taylor.

Mr. Taylor. station work at any rate, we may find ourselves getting landed into difficulties owing to the cost of the booster. Where there is a single booster upon which to carry the charge and discharge over rather wide limits, the cost is a very serious matter, and I think that unless we adopt some such method (viz., series-parallel connection of the boosters) as I have formerly described, we shall get into difficulties in competition with regulating cells. In Germany regulating cells have come along very fast, and there are now many very perfect forms of regulating switches for working in conjunction with supply circuits; these switches are coming into this country. British manufacturers of boosters will, I think, have to look to their laurels, because if they stick to their present methods of booster control they will find that the cost of the booster plus the battery is really slightly more than the cost of the regulating cells plus the battery. It is only by adopting some such method as I have suggested, which reduces the power of the booster by something like 70 per cent., that it is possible really to compete successfully with Continental methods. I do not see that there is any difficulty in applying the series-parallel method to automatic boosters, provided we can get a suitable turnover switch —one that will enable us to turn over at particular times, when occasion requires, from one connection to the other. I think it is quite practicable to design such a switch. As regards the value of the saving introduced by the battery, in the paper I read a year ago,* I think I may claim to have shown there that, for a triangular peak, having a base of about 2 hours, the saving works out, as compared with extra steam plant, all things considered, at about £1 per kilowatt per annum; and if the peak has a 4-hour base, the saving works out at about 10s. (ten shillings) per kilowatt per annum. From that it would be expected that when we come to short peaks like those discussed in the paper, the saving would run up rapidly, but this is not so, because the kilowatt output of the cells does not run up proportionally as the time is reduced, and we very soon come to a limit where the safe current for the cell, and for the booster, is such as to limit the output of the battery, and we get no further saving. No doubt, shorter "time" peaks than the above will show a greater saving than £1 per kilowatt per annum where they would be sufficiently severe to cause serious engine losses if there were no battery. It must, however, be remembered that if they are only of very short duration, no saving can be credited to the battery on account of boiler plant or boiler stand-by losses. The above figure is, I believe, quite safe to employ for "time" peaks where we are dealing with a motor load; but not for a pure lighting load, which is dependent upon fogs and requires a large margin in the battery. But where we have a motor load, where the coming on or off of a fog does not alter the distribution of the load, I think we are quite justified in stopping for a time the installation of any further steam plant in a station which is getting filled up, and putting in batteries for taking up part of the load, and I believe that the above

* *Proceedings of the Institution of Electrical Engineers*, vol. 47, p. 393, 1911.

saving will then be realised. As regards automatic boosters for alternating-current systems, I do not think there is a great scope for them on our large systems of alternating-current general supply. In Birmingham we started first of all without any automatic regulator for our alternating-current heavy loads. We have got there some individual installations up to 1,000 k.w. We very soon found that we had to have a Tirrill regulator, because of the fluctuations of the loads, but I do not think the economy introduced by having that regulator would have paid for a battery. I think that, so far as economy is concerned, we have been doing quite right in going on without any battery on the alternating-current side when it is merely a question of regulation for instantaneous peaks; and it is only in cases such as winding installations, or in stations with an irregular load at various parts of the day, that it is absolutely indispensable to have a battery. There is just one more point to which I should like to refer. Where the question is one of improving the power factor of alternating-current supply by using synchronous machinery in conjunction with a battery, *i.e.*, using the battery to find a load for the synchronous machines, so that the necessary leading current can be got out of the synchronous machines without having to build a large machine for the purpose, I think that, if we have alternating-current apparatus in a sub-station so acting that a change of the power factor first of all affects the excitation of the synchronous machine, and, secondly, operates on one of these types of automatic boosters to compensate for the change in voltage caused by varying the excitation of the machines (so that the battery still goes on charging and the current keeps more or less constant), we have then a sort of ideal way of compensating for the power factor, and one in which we have the energy stored up in the battery and available for the time of peak load if necessary. Mr. Taylor.

Mr. H. BURGE: With reference to the Pirani type of booster, where the B coil is excited from the battery and is consequently weakened when discharge takes place, it is stated at the bottom of page 289 that there is nothing to limit or prevent the discharge increasing without end, and the battery tends to take the whole load off the generator. This statement is not at all correct. In practice in a properly designed booster of this type, especially if constructed with interpoles, there is present to hand a convenient and easy method of entirely overcoming the difficulty mentioned. This is done by setting the brushes forward, so that an armature action is set up which demagnetises the field and reduces the booster volts by a fixed amount for, say, every 100 amperes flowing in the armature. This effect is augmented by the presence of the interpoles. The brushes can be adjusted to suit any conditions permanently, and the arrangement is very effective, because the rise in the current of the booster armature is a great deal more rapid than any rise or fall of the current in A or B coil. If we make these adjustments the two-coil type of booster gives such good results that the extra complications which have been introduced into other types of boosters are really not worth having, and they only cause unnecessary sluggish- Mr. Burge.

Mr. Burge. ness. The addition of the coil marked D merely reduces the diverter size and the field copper on the booster, and this appears to be the only reason for adopting it. With reference to Mr. Highfield's remark that a shunt generator should be adopted when a battery and booster are contemplated, although it is very desirable it would hardly do in the case of traction work, where over-compounding is nearly always necessary, and there are no means of making a shunt machine over-compound. On page 317, Fig. 18 is put forward as representing a Crompton winding scheme with an equalising battery. The diagram and description represent fairly accurately the action, but the whole thing really boils itself down in practice to the following sketch: Taking the case of a 3-phase supply, the 3-phase motor A drives the double machine B, which is a form of C.M.B. converter, with the lower portion across the battery. The upper part forms with the lower part a Ward-Leonard motor-generator, and operates the winding motor on the up-and-down boosting principle, that is to say, at starting the top portion opposes the battery and reduces the voltage

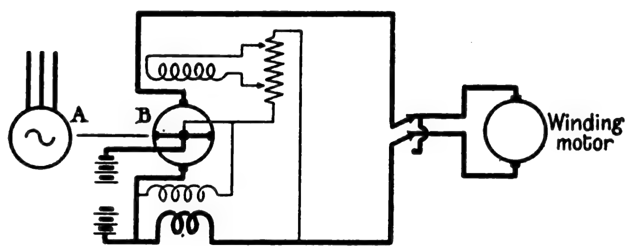


FIG. A.

on the motor, whereas at full speed this part boosts up the battery voltage to twice the amount. The author states that such an arrangement cannot be made to equalise the load very satisfactorily. I cannot agree with him, because by suitable series winding on the lower part of the double machine—this series winding being in series with the winding motor—the plant can be made to take a constant load from the mains continuously within 10 per cent. of the normal. There seems to be a rooted objection by colliery engineers to put in batteries at all, and it is hoped that this paper will induce some of them to give the matter a trial.

Mr. Jenkin. MR. B. M. JENKIN: There are one or two points to which I should like to refer. The question of time lag is certainly a most important one in the diverter type of booster. Before the Entz booster came out I had some experience of a booster of a diverter type, and I experienced great difficulty in trying to get the lag reduced. I failed to do so for the very reason explained in the paper, but luckily in that case it did not matter. It was at a sub-station where the battery and booster were working in parallel with motor-generators. The load was an

Mr. Jenkin.

extremely rapidly fluctuating one, being a railway load, and what really happened was that the momentary increase in current when it came on was supplied by the generators of the motor-generator plant. They took the momentary increase of load, sometimes going up to 50 per cent., even in emergency up to 100 per cent. overload for a second or two, while the booster was picking up its field and making the battery give the overload. But we found that this momentary overload on the generators did not matter; the machines were designed to take it without sparking at the commutators, and being for such a short period the heating effect was practically negligible. For that reason the lag of the booster did not matter luckily, because we could still run the motor-generators at full output and let them take the momentary overload for a second or two. But it occurred to me afterwards that we might have gone to a considerable amount of unnecessary expense in putting in a booster with a very small time lag. We went to the expense of laminated fields and separate exciters, and all the complications to be seen shown on the diagrams, with the very object of getting the motor-generators uniformly loaded and making all the peaks come on the battery. We did not entirely succeed, but it did not matter. We might, however, have saved perhaps a great deal of expense on the booster by frankly admitting beforehand that we would let the motor-generator plant take the momentary peak so long as the time lag was limited to a period that prevented the over-heating of the motor-generator plant when run at full load between the peaks. I hope the author will give us, if he has not done so already in his paper, some comparison between the actual time lag that occurs between the diverter type of booster and the separately regulated booster as in the Entz type and the Tirrill type. There is no doubt that the diverter type of booster involves a considerable complication and expense. There are laminated fields; usually a separate exciter; a diverter resistance, and very heavy leads between the diverter and the booster field. That circuit through the booster has to be kept of low resistance in order to keep the diverter of low resistance, and therefore not lose much power in the diverter. All that runs to great expense. If that type of booster is compared with the one controlled by the Tirrill regulator it will be seen that in the latter we have a plain generator with a shunt field without any series winding—in fact, the simplest arrangement so far as the booster is concerned that can be got; it is simply a generator with a shunt field. It is clear that as the size of the battery is increased—and it is now the fashion to put in bigger and bigger batteries in stations to take the peak load both momentarily and for longer periods—the size of the booster increases, and therefore the cost of it increases; and if as good results can actually be obtained with the Tirrill regulator as with the diverter type of booster it would seem that the booster with the Tirrill regulator is going to be the better on account of the cost. I think if the author can give us some comparative figures as to the cost of the different types of boosters it would be of much value. There is just one other point I want to refer

Mr. Jenkin. to, namely, the question of compounding traction generators when worked in parallel with a battery and booster that are supposed to keep the load on the generators constant. If the battery booster does its work properly there is no fluctuation in current on the main generator to make it over-compound. I tried in one case an arrangement which, on the whole, worked quite satisfactorily, and which consisted simply in putting the series winding of the generators not in the generator circuit, but in the main return circuit. The fluctuation of current in the main return circuit over-compounded the generators, but the current through the generator armatures could remain constant. The battery with its booster take the fluctuations of load so as to maintain the generator armature current constant, but the fluctuation of current in the generator series winding alters the generator voltage so as to give an over-compounding effect.

Mr. Allingham. Mr. G. C. ALLINGHAM (*communicated*) : The author has given a very complete description of practically every known type of automatic reversible booster; but I am unable to agree with his explanations of the working of many of the boosters. For instance, he has placed the Highfield and E.C.C. boosters in a class by themselves, although, as I shall show presently, they are merely varieties of the differential type, while, on the other hand, he has included the Lancashire booster with the differential boosters, although the former works on an entirely different principle. I would suggest that a better way of classifying automatic boosters would be as follows: (1) Boosters of the differential type, the essential principle of which is that they give a boost approximately proportional to the current by which they are controlled. These boosters are controlled by the line current, and have no direct tendency to keep the generator current constant; they only do so more or less imperfectly as the incidental result of giving a boost which is approximately proportional to the line current. This class would include, besides the plain differential booster, the Highfield, Pirani, Crompton, and E.C.C. boosters. (2) Boosters which are controlled on what might be called the equilibrium principle; with such a booster any variation in the value of the current by which it is controlled produces a disturbance of the equilibrium of the controlling system, which is thereby set into operation and continues to operate until its equilibrium is restored, and therefore always tends to keep constant the current which controls it. These boosters are controlled by the generator current and have an inherent tendency to keep the current drawn from the generators constant under all conditions. In this class would be included the Lancashire booster, as well as those controlled by the various kinds of external regulators, such as the Entz, Tirrill, Taylor-Scotson, Brown-Boveri, and Tilney.

I also cannot agree with the statement made in the paper that a plain differential booster with its separately-excited or shunt coil connected across the battery, instead of across the busbars, as shown in Fig. 2, is unstable in working. It is true that when, owing to an

Mr. Allingham.

increase in line current, the series field A increases and causes the battery to discharge, the separately-excited field B at the same time diminishes slightly, owing to the drop of voltage of the battery; this decrease of field B is, however, very small compared with the increase in field A, and is quite incapable of causing any "building-up" effect. This may, perhaps, be seen most readily by taking a numerical example. Suppose, on a 500-volt system, a sudden increase in the line current increases the series field of the booster so as to give the machine a voltage of 50 in the discharge direction, thus causing the battery to discharge and its voltage to drop by 50 volts, or 10 per cent. This reduces the strength of the separately-excited field B by 10 per cent., and increases the voltage of the booster by 10 per cent. or 5 volts; the discharge is increased and the battery voltage drops 5 volts or 1 per cent., which produces a further increase of 1 per cent. in the booster volts, a further drop of $\frac{1}{10}$ per cent. in battery volts, and so on. The effect thus dies away very rapidly, and the maximum value which the booster voltage can reach is $50\left(1 + \frac{1}{10} + \frac{1}{100} + \ldots\right)$, or 55·56 volts. As the battery voltage always drops by only a small fraction of its value, the increase in booster field is always represented by a rapidly diminishing series of this kind, so that it is impossible for the booster field to increase without limit, as stated in the paper; as a matter of fact, it is found in practice that it makes very little difference to the working of the booster whether the separately-excited coil is connected across the busbars or the battery, and that the latter arrangement certainly does not render the booster unstable in working.

The case is different, however, when a third or self-exciting coil is connected across the brushes of the booster itself, as shown in Fig. 3 in the paper. In this case the voltage of the booster can increase without limit, as may be seen by taking another numerical example. Suppose a sudden increase in the line current to produce an increase in the series field A (Fig. 3), sufficient in itself, without the assistance of the self-exciting coil, to give a boost of 10 volts in the discharge direction, and that this potential difference of 10 volts applied to the self-exciting coil D increases the voltage of the booster by a further 10 volts. The total voltage of the booster is then raised to 20 volts, the potential difference across the self-exciting coil is raised by 10 volts, the voltage of the booster is raised another 10 volts, and so on without limit until the fields approach saturation. If the self-exciting field were made proportionately stronger, as compared with the series field, the booster voltage would increase more rapidly still. If, on the other hand, the self-exciting field were made weaker, the booster would no longer build up without limit, but it can readily be seen that the compensating value of the self-exciting field falls off rapidly as it is made weaker in proportion to the series field, and if it is made weak enough to avoid all risk of instability under any conditions, it has but little effect on the regulation of the machine, so that there is in practice little or no advantage in employing it. It is,

Mr. Allingham.

no doubt, for this reason that Messrs. Crompton have for some years past given up making boosters of the "three-coil" differential type (which is nevertheless described by the author as the "Crompton" booster), and now make the type of booster shown by the author in Fig. 2, and called by him the "Pirani" booster.

The author, by the way, is mistaken in stating that iron-aluminium cells are employed with the Pirani booster for the purpose of limiting its instability; as a matter of fact, they are employed for an entirely different purpose—namely, for rendering the characteristic curve of the booster unsymmetrical on either side of zero, so that the state of charge of the battery may be compensated for by a hand adjustment. The iron-aluminium cells are connected up in a different way to that shown by the author in his Fig. 4; in fact, in the arrangement shown

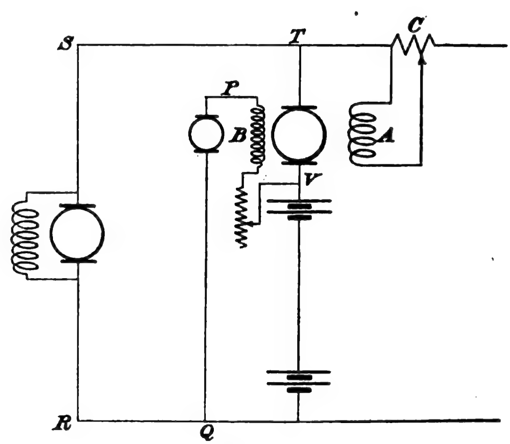


FIG. B.

by him the iron-aluminium cells would have no effect, and the result would be the same if these were omitted altogether, and one of the rheostats were inserted permanently in the exciter circuit.

The Highfield booster, when worked with a battery which is taking the whole load by itself, no generating plant being run, is controlled primarily by the line volts, which it always tends to keep approximately equal to the exciter volts. If a series-coil connected in the line circuit be employed, its effect is merely to compound the booster so as to compensate for drop in the line. When working in parallel with generating plant, however, the Highfield booster cannot be worked satisfactorily in this way, and under such conditions it is controlled by the field coil in series with the line, which then no longer acts as a mere compounding coil, but converts the machine into a differential booster controlled by the line current. In the ordinary differential booster the series field is balanced by an opposing separately-excited

Mr. Allingham.

field ; in the Highfield booster a corresponding balance is obtained by reducing the voltage of the exciter below that of the line by such an amount that the difference of the line voltage and the exciter voltage applied to the coil B (see Fig. 6 in the paper) will produce a field which is equal and opposite to that of the series coil A when the line current is equal to the desired generator current. By reference to Fig. 6 it can readily be seen that the exciter coil B is connected across the exciter, the generator, and the booster in series in the circuit which I have marked P Q R S T V on Fig. B, which is a copy of Fig. 6 in the paper ; the voltage applied to the coil B is therefore equal to the algebraical sum of the voltages of these three machines. Of these the exciter voltage and the generator voltage are practically constant, and the excitation of field B is thus the resultant of two elements, one of which is constant and the other proportional to the booster voltage. The first of these elements is equal to the algebraical sum of the exciter voltage and generator voltage, and produces in coil B a field equal and opposite to that of coil A ; this element is the exact equivalent of the separately-excited field of a differential booster. The second element, which is proportional to the booster voltage, is the exact equivalent of the self-exciting field of the "three-coil" differential booster in Fig. 3, and has the same tendency to increase progressively. For suppose, owing to an increase in line current, the battery begins to discharge : the battery voltage drops, the booster voltage increases, the field B is increased by a corresponding amount causing a further increase in the booster voltage, an increase in the discharge and a corresponding drop in battery voltage, the field B is increased again, the booster voltage is further increased, and so on. The machine thus has a tendency to "build up" ; if the series coil is made weak, and the exciter voltage made nearly equal to the line voltage, the self-exciting effect is increased and the working of the machine becomes unstable. If, on the other hand, the series coil is made strong, and the voltage of the exciter is reduced considerably below that of the line, the compensation is but little better than that obtained with the plain differential booster. The Highfield booster, when working under these conditions, is thus the exact equivalent of a "three-coil" differential booster, the functions of the separately-excited and self-exciting coils being combined in the single coil B by the agency of the exciter ; it is regulated in the same way and shares all the defects of the "three-coil" differential booster, including its instability.

The E.C.C. booster is the exact analogue of the "three-coil" differential, the potential-control element in the Highfield booster being entirely absent. The functions of the separately-excited and self-exciting fields are again combined in coil B (Fig. 7), the voltage across which is equal to exciter voltage $\pm$ booster voltage ; the exciter voltage produces an element in the excitation corresponding to the separately-excited field, while the booster voltage produces an element corresponding to the self-exciting field. This booster has exactly the same properties in every respect as the "three-coil" diffe-

Mr. Allingham. rential. The analogy between the Highfield, the E.C.C., and the "three-coil" differential boosters may be illustrated in another way. In Fig. 6 the potential difference between points P and T (*i.e.*, the line voltage *minus* exciter voltage) is constant; the same effect would therefore be obtained by connecting P and T together, the exciter being dispensed with, and adding another coil excited by a constant voltage and having the same magnetising effect as that produced in the coil B by the voltage between P and T. We then have the "three-coil" differential booster. Or, again, the same effect would be produced by connecting between the points P and T an exciter generating a constant voltage equal to the difference of potential between P and T; we then have the E.C.C. booster.

The Lancashire booster, although it bears a superficial resemblance to the "three-coil" differential booster, really works on an entirely different principle. Its series coil is connected in the generator circuit instead of in series with the line, and that, although apparently a trifling change, entirely alters the way in which the machine works. When the generator current is at the desired mean value the series field A (Fig. 5) balances the separately-excited field B. If the outside load increases the generator current is increased at first; this raises the series field of the booster and produces a discharge boost; as soon as the booster begins to give voltage the self-exciting coil D connected across the brushes is excited and raises the booster voltage, this again increases the self-exciting field, which continues to "build up," as in the case of the "three-coil" differential booster. But mark the difference. As the discharge boost increases the battery takes the load and the generator current drops back. Supposing it were to drop below its original predetermined value, field A would become weaker than field B, and the resultant of these two fields would reverse and oppose field D and would resist its building up, for the more field D tended to build up and cause load to be taken off the generator the greater the opposing differential field (B—A) would become. The result is that the building up of field D is limited, and can only continue until the generator current is restored to its normal value; as a matter of fact the generator current cannot actually be brought back quite to the normal value, as field A would then cancel field B, and there would be no resultant field to determine the excitation of the self-exciting field D. Hence the generator current is always a little above the normal when the booster is giving a discharge boost, and a little below the normal during a charge boost. In other words, the generator must of necessity take a proportion of the fluctuations of the outside load; but if the booster is properly adjusted this proportion is very small, the variations of the generator load being only a few per cent. of the variation of the outside load. The self-exciting coil, which produces instability in the differential boosters, does not do so in the Lancashire booster, which is perfectly stable in working under all conditions. On page 292 of the paper it is stated that with diverter boosters the diverter resistance should be fixed, and that the generator

Mr. Allingham.

current should be adjusted by altering the separately-excited field only. This is theoretically correct for differential boosters, but with the Lancashire booster, on the other hand, it is theoretically correct to adjust the generator load by adjusting the resistance of the diverter, and to keep the separately-excited field constant.

The author makes a great point of the simplicity of the Entz regulator, but the simplicity of its internal connections is of small importance compared with the complexity of the external connections required with it. In the author's diagram the regulator is shown, "for simplicity," connected across the whole battery, but in actual fact (as was mentioned very casually by the author) it has to be connected across a small portion of it, since the carbon piles have comparatively low resistance and are therefore only suited for working with low voltages. In order to avoid discharging one group of cells more than the remainder, tappings have to be taken off at intervals all round the battery and a multiple-way switch has to be provided by which the exciting circuit may be connected alternately to each group of cells in turn. We therefore have a number of small wires running into the battery-room constantly alive and exposed to the action of acid; we also have the multiple-way switch which the attendant has to remember to change over at regular intervals. All this small wiring is not required for any of the other types of regulator described, since they work across the full supply voltage. Nor are the other types of regulator any more complicated to handle and operate, in actual use, than the Entz. To take the best known example, the Tirrill regulator is, as is generally known, perfectly simple to handle, and actual experience has shown that the Tirrill battery-booster regulator is just as simple to handle as the ordinary Tirrill voltage regulator. The form of Tirrill regulator that is actually employed in this country for battery-booster control is, as a matter of fact, quite different from those shown in the diagrams given in the paper (Figs. 11 and 12) and much less complicated. The diagram of the Taylor-Scotson regulator in the paper (Fig. 13) is also wrong; in fact, a regulator as shown in that diagram would not reverse the voltage of the booster at all, but would only vary it up and down between certain limits. It is stated that the stops E and F above the lever of the Entz regulator enable the charge and discharge battery currents to be limited. This is not, however, strictly true; what these stops actually limit is the booster voltage, which is not the same thing, since the charge or discharge battery current depends on other factors as well, such as the state of charge of the battery and the line voltage. Further, the use of these stops would, it seems to me, entirely prevent "overshooting" and nullify the special advantage thereby obtained. The range of other types of regulator can also be limited, if desired, by means of tappings on the rheostats. It is also put forward as a special feature of the Entz system that there is no "complicated system of field windings to be designed in accordance with exact theory," but this feature is shared equally by all the other external regulators, and

Mr. Allingham.

even by the Lancashire booster, which does not require any "patient adjustment on site."

With regard to the Hucknall Colliery installation, I should like to say, as having had a good deal to do with the design of that plant, that the arrangement shown in the author's Fig. 22 was actually considered. In this case, however, matters were complicated by the fact that the alternator and the converter were at opposite ends of the high-tension transmission line, a mile and a quarter long, so that the controlling device in the generator circuit and the field of the converter which it would control would have had to be separated by the same distance. It would not have been impossible to control the field at this distance, and means were actually designed for the purpose, but it would have been an experiment, and the complication and cost (including that of the pilot wires which would have been required for the automatic control circuit) would not have been justified in so small an installation.

Mr. Scott.

Mr. E. Kilburn Scott: Any one reading the paper must have been struck with the difference between the diagram shown at the beginning and the diagrams in the latter half of the paper. Fig. 1, for example, shows the ordinary differential type of booster, and it is exceedingly simple as compared with many of the others. All the types are at work somewhere, I presume; at any rate, the simplest of all the differential type is working very well. It may not give the straight voltage line which the inventors of the complicated devices are trying to obtain, but it knocks off a large portion of the peaks, and I think that is all that is wanted in most cases; at any rate, it is all that is wanted for crane work, hauling, winding, and other similar variable loads. The reference in this paper about the plant at the Gary steel works, Indiana, is of special interest. It appears that the Gary plant was originally put down to work entirely with a flywheel storage, but they found it would not do, and so storage batteries and reversible boosters were put in as well. I went round the Rothesay Dock the other day, and must say that it is a particularly fine installation. Reversible boosters and battery plant would have to be very well thought out and installed to compete with it. In this connection there is one thing which I do not think could be done so well with a battery and boosting plant. Each of the large hoists for lifting trucks of coal and tipping them is supplied with current from its own dynamo coupled to the main engine, and the storage flywheel is mounted on the same shaft. Now a pair of small leads is carried from each dynamo right on to the top of each coal hoist where the motor is situated. The regulation of speed is then simply effected by a small resistance close to the motor.

To give the same amount of speed regulation with storage batteries there would presumably be an accumulator switch and a motor to run the switch along. When the peak load comes on at Rothsay the flywheel gives out the extra power, and in doing so its speed diminishes from about 475 to 420 revs. per minute. To give a level voltage for the lighting and small-power cranes there is a dynamo between each engine and the storage flywheel. This dynamo has its field

current governed by two exciters, the voltages of which oppose each other. One exciter is separately driven by a small engine and gives a higher voltage than the other. The second exciter is belted to the dynamo shaft. Now, when the storage flywheel is giving out energy its speed falls, and the voltage of the belt-driven exciter falls also, consequently there is a greater difference of potential between the two exciters and more current goes through the dynamo field coils, so keeping up the voltage at the dynamo terminals. The Hucknall Torkard installation I have also seen, and believe it is the only colliery plant in this country which has a large storage battery and reversible booster for running haulage gear and similar variable power work. An interesting point about it is that the storage battery and booster are a considerable distance away from the power house and on the top of a hill, so they get very little attention, and they do not appear to want any. Of the various forms of boosters other than the differential, the Entz appears to be efficient and simple. It depends primarily on the two squeeze carbon resistance piles. These resistances at first sight may seem rather unmechanical and liable to change, but, as a matter of fact, they seem to have an almost unlimited life. For example, some squeeze carbon resistances at Finsbury Technical College are at work to-day just as they were made twenty-nine years ago by a member of the staff. Mr. Taylor said that the reversible booster in the Birmingham power house has to be protected by a switch, which cuts it out of circuit at the highest load conditions. It is, of course, an ordinary commutator machine, and, in so many words, is not robust enough. Therefore why use a commutator machine? Why not put in a homopolar? The homopolar, being a low-voltage machine and able to give very large currents, is the ideal machine for boosting in connection with storage batteries. Why it has been overlooked for such purposes one cannot quite understand. One feature about the homopolar machine, which may have a useful application some day, is the easy way in which its voltage can be altered by cumulative or differential compounding. Merely moving the brush leads so that current flows along them in the same direction or in the opposite direction to the adjacent field coil will alter the voltage. Mr. Scott.

Mr. W. M. MORDEY: May I say a few words about the first use of carbon resistances in regulators? I think we ought to remember that the carbon regulator is a very old idea. I think one of the earliest forms based on the effect of pressure was the carbon telephone of Edison, where he allowed the telephone disc to press against a carbon button, and so by variations of pressure to alter the resistance slightly and thus vary the current in the line of the other telephone. That was, I think, in the late seventies. In 1881 Brush patented the well-known old Brush regulator, which, perhaps, some of you are not old enough to remember. It was much used, and is the father, or the grandfather, of all the carbon-pile regulators of to-day. Those who remember the Brush regulator will know that a pile of carbons, or several piles of Mr. Mordey.

Mr. Mordey. carbons, in series or parallel—little thin square plates—rested on a lever controlled by the current, altering the resistance of the carbon, and shunting more or less current from the series field winding according to the pressure exerted. The same principle has since been successfully applied to many other purposes, but I think we should not forget its origin.

Mr. Siddeley. Mr. H. C. SIDDELEY (*communicated*): Referring to the remarks on the question of the diverter in connection with the Lancashire booster, it is arranged to divert as little a portion of the main current as is possible, so that the turns in the series winding are a minimum, thus decreasing the self-induction and increasing the rapidity of the building-up of the booster. In adjusting the generator load with the Lancashire booster, use is made of both the intermediate stops on the series diverter and on the shunt coil B—the coarse adjustment being made by the diverter and the final regulation being done on the shunt. The diverter is designed so as to have the stops corresponding to the loads of either one, two, three or more sets running in parallel. The point mentioned in the paper, of the boosters of this type being adjusted to share the load with the generator, is often a great convenience, as there are often times when the peaks on the load are too great for the battery alone to cope with. It is then a decided advantage to adjust the booster working that the overload capacity of the dynamos is brought into use—that is, momentarily—in order to ease the violent discharge, which would otherwise have to come from the battery alone. This proportion can be regulated to almost any degree by an adjustment of the auxiliary shunt coil marked E in Fig. 5. In discussing this type of booster running in parallel with compound-wound generators, the writer has omitted to allow for the motor increasing in speed due to the higher voltage, and thus getting the necessary increase of volts as the voltage rises on the busbars: the auxiliary coil D also compensates immediately and automatically for any rise in voltage the busbars which takes place. As a matter of fact, the Lancashire booster works relatively better than any other type when running on an over-compounded supply. It is, however, always necessary when running with over-compounded generators, that the connections of the dynamo be so arranged, that either the total return current, or the total feeder current, goes through the series coil, otherwise as the dynamos are all giving constant current, there will be no over-compounding effect. It is often necessary to run over-compounded generators on a traction load, for the reason of the lay-out of the feeders, and this is entirely independent of the question whether a battery is used or not. Fig. 8, as showing a chart of the working of a diverter booster on a traction circuit, is not a representative one, as no one expecting to get good results would so arrange the running of his station that he got his battery fully charged at such an early stage, there being two reasons against this: first, that no booster would regulate well where there is practically no difference in volts between the battery and busbars; and secondly, that all the current

that is available for charging the battery is wasted, which makes running in this way very uneconomical. Mr. Siddeley.

With reference to the use of an exciter with a Lancashire booster; when an exciter is used with the Lancashire system it is not the case that this necessarily makes the booster more sluggish, for during the same time that the exciter is building up and the volts are rising, the same thing is taking place on the fields of the booster, and therefore the maximum effect on the booster field is obtained practically instantaneously with the maximum effect on the exciter. This is as shown in the Manchester Corporation boosters, where all three machines may be excited in parallel from one small exciter set, and the results there obtained are certainly as good as with any equally large boosters.

There is a great advantage in safety in the use of a system such as the Lancashire, as when the machine is once in service nothing can ever go wrong or stick, as in the case of outside regulators. These regulators must be notoriously weak links in the chain, for if an automatic regulator should stick, say, when the battery is charging, the effect on the station would be disastrous when an overload came on to the feeders, as the generators would have to take the overload and go on charging the battery at the same time. Such a thing cannot possibly happen where the regulation is entirely effected by the field windings. This is a very important point, and seeing that batteries are put in as an assurance against failure of supply, it is important that the booster system used should not take away from this safeguard.

With reference to the use of synchronous motors driving boosters, the St. James and Pall Mall Company will shortly have such a motor, of a self-starting type, driving their booster, and it is intended to use this during the daytime when charging, and to use the motor also for the purpose of raising the general power factor of the system by over-excitation.

Mr. C. J. HOPKINS (*communicated*): On page 297 the author states that the presence of a heavy flywheel on the engine also affects the quality of the results with some boosters in the same way as over-compounding on a generator, or the governor of an engine attempting to make the engine follow the load. This is true as far as the results recorded in the generator load chart are concerned. However, the flywheel effect is an efficient one, since it does not make an uneconomical demand upon the steam consumption, whereas over-compounding on a generator or the governor of an engine does, so that the results are not strictly comparable, and there seems to be no question as to the desirability of a flywheel as implied in the paper, even though it may appear to interfere with the evenness of the generator load. Mr. Hopkins.

DISCUSSION BEFORE THE MANCHESTER LOCAL SECTION ON 28TH NOVEMBER, 1911.

Mr. E. C. MCKINNON: It is interesting to notice how widely booster practice varies throughout the world. In the United States Mr. McKinnon.

Mr. McKinnon.

boosters are employed to an enormous extent. In this country boosters are also largely employed. In the colonies, in Japan and China, numerous battery booster plants are in satisfactory use. On the Continent, however, boosters are quite out of favour. In discussing the matter with the chief engineer of the Stockholm Corporation this year, I gathered from him that Continental engineers consider they can obtain almost as good results by employment of end cells with regulating switches and by designing their generators with a drooping characteristic. This engineer stated that in travelling through Sweden, Denmark, Germany, and Switzerland, he had been surprised at the number of automatic regulators installed on one of the three systems, Thury, Tirrill, and Trumpy, and quite as much surprised at the number of cases in which the regulator was not working. Apart from the theory of reversible boosters, good design plays an important part in the successful results obtained from the booster. Another matter affecting the results obtained with boosters is the manner in which they are operated. I have visited installations where the booster has given poor results simply through inattention to keeping the commutators clean, or the regulator free from dust and grit. The engineer in one of the North Wales Corporations told me that two competing firms invited him to view installations where they had put down battery booster plant. When he arrived, however, he found in one instance the booster was not running, and on inquiring for the reason he was told that it was cheaper to let it stand.

Mr. Cooper.

Mr. A. G. Cooper: I have not come here to take part in the discussion, but want to hear something about the working of these plants from users, who seem, so far, very shy. I have no battery now at Colne; it was scrapped a long time ago, but I am very pleased to hear that batteries are so much improved, although it would take a lot to convince my committee that this is so. The battery at Greenock is mentioned in the paper. I remember some three or four years ago discussing the merits of it with a gentleman who is present to-night, and told him that Greenock seemed to have saved more coal than they ever ought to have burnt. On examining the *Electrical Times* tables for the different years, we found that the coal costs had gone down, but that repairs and maintenance (I concluded battery attendance and upkeep) had gone up so that there was no gain. I also compared my own costs (without a battery at all), and they were, if I remember rightly, lower than Greenock on a considerably less output, so I told him that I could not see what I was to gain by spending money on a battery.

Mr. Wheelwright.

Mr. P. P. Wheelwright: As a user of an "Entz" booster and regulator, I have found it has the following advantages: It is (*a*) quick in action; (*b*) simple in manipulation; (*c*) maintenance is very small. In the running of a large central station it is most valuable financially. The working results, after two years' use, were most satisfactory, and I am pleased to state that the coal consumption per unit has been reduced, the maintenance cost of engines, owing to constant loads, has been brought down, and the voltage line very much improved.

Mr. Worrall.

Mr. G. W. WORRALL: The author has collected together in convenient form a great deal of information. It is, however, a pity that he has not extended the scope of his paper so as to include, in the form of tabulated results, curves, and instrument charts, more information on the actual results obtained in practice by the different classes of booster. The only two tables which are given are not at all comparable, as they show the influence of the two types of boosters from different points of view, while all the charts given do not appear to be selected with a view to showing the good points of the various machines to which they refer. The author has scarcely emphasised sufficiently the difference in the stability of a booster, when the main series coil is in the generator circuit and when it is in the feeder circuit, and I think he has made too much of the rise in the generator current for which balance is obtained when the generator is over-compounded. The diagram given in Fig. 2 for the Pirani booster is not quite up to date, for the Felten and Guilleaume Lahmeyerwerke * claim to have overcome the difficulty described in connection with this machine. According to the article referred to, the booster is excited by a separate exciter which has one field winding shunted across the mains and a second field winding in parallel with a diverter. In addition to this means of excitation, the booster itself has a second field winding shunted across the mains. This second field is always excited, and in order that the booster may generate no E.M.F. on normal load the exciter must provide an opposing field. Thus the two exciter windings do not cancel each other and the exciter field may be worked at any desired part of the magnetisation curve. The exciter is usually operated on the knee of the curve, and hence a rise in the main current does not cause a proportionate rise in the booster volts and a continual increase in the discharge rate. When the main current falls below the normal value the magnetisation of the exciter is on the straight-line portion of the curve and the booster volts drop rapidly with a corresponding increase in the rate of charge. In this manner, it is claimed, the ratio of discharge current to charging current for a given change in the main current may be adjusted to any desired value, even to as low as 0·5. The magnetic arrangement just described has the same effect as the electrolytic cells and resistances shown in Fig. 4. Such cells, however, would probably require considerable attention and Siemens' † have tried iron wire resistances. The resistances are placed in the various field-coil circuits, and by employing different resistance values and temperature rises the currents can be controlled as desired. The descriptions given of batteries and boosters on alternating-current systems are of special interest. There is a system in use at Elmira, New York,‡ in which the diverter principle is adapted to alternating-current in a very ingenious way. The load consists of mixed direct-current and alternating current, but the direct current is supplied from the alter-

* *Elektrische Kraftbetriebe und Bahnen*, vol. 8, p. 421, 1910.
† *Elektrotechnische Zeitschrift*, vol. 30, p. 297, 1909.
‡ *Electrical Review*, New York, vol. 53, p. 440, 1908.

Mr. Worrall. nating-current bars through rotary converters, and is controlled as an alternating-current load. All the circuits of fluctuating load are coupled to an auxiliary alternating-current busbar (the direct current through the rotaries). The battery and booster are, of course, on the direct-current bars and take the excess direct-current load, but when the battery discharge exceeds the direct-current demand, it feeds into the alternating-current side through inversion of the rotaries. The booster is of the usual diverter type, but the regulating coil is connected to the direct-current side of a small rotary converter which is fed with alterternating current by a series transformer in the auxiliary alternating-current busbars. The secondary of the transformer is fitted with tappings, so that the regulation may be varied at will. The current supplied to the regulating rotary is proportional to the true energy component of the variable alternating-current load.

Mr. Frith. Mr. JULIUS FRITH: The author has brought out very clearly the inherent advantages and disadvantages of the various types of boosters. If the machine only gives the correct results as a steady condition and neglects the exponential terms, it cannot possibly be very quick in its action. The various time lags all add up, the current takes a certain time to start round the magnets, the flux only follows the current gradually, and so on. With the Entz and Tirrill type of regulator the actual change effected is the initial part only of a much greater change, and is therefore completed in a much shorter time.

Mr. Stewart. Mr. C. L. E. STEWART: My experience of the Lancashire booster has been a very happy one. I have had one running for 2¾ years, and I do not think it has stopped for more than 24 hours during the whole of that time. I am rather surprised to hear something said about that type of booster not regulating quickly. I always thought ours was remarkably quick in acting, and our voltage on the traction system is good; in fact, we have a number of lighting consumers supplied off the traction circuit and we never get any complaints, and according to the chart it is a straight line. We do not get necessarily a dead steady load by our generator. We do not want it, because the fluctuation is more than the battery could take charge of. We get a very heavy duty out of our battery all day and night, and I would like to mention the excellent condition the battery is in, in spite of it working all day at the 1-hour rate.

Mr. Wilkinson. Mr. H. T. WILKINSON: I would like to know why it is we do not see any greater developments in the regulation of alternating currents by boosters in this country. Of course they are more advanced in America, probably because there is more scope.

Mr. Atchison. Mr. C. C. ATCHISON: I would like to have heard something from the other makers of boosters, for although, in my opinion, Mr. Rankin has been extremely fair, yet we have only one side of the case, and the "Entz" booster seems to have taken the lead. I notice Mr. Stewart has referred to, and tried to stand up for the Lancashire booster, and perhaps it would have been interesting to some other station engineers to have heard other views on that and other types of booster.

With regard to the "Entz" booster and rapidity of action, I am very doubtful whether absolute rapidity of action is always essential. I do not think it always is, and believe that although a very good case may be made out for the "Entz" booster in certain positions, yet other boosters have their advantages in others. We hear the question of Greenock as to whether the interest, sinking fund, capital expenditure, and the maintenance of the battery has not counterbalanced the benefit in the coal costs. That is purely a question of time, but I think the strength of the argument in favour of the use of batteries and boosters lies in the fact that it is not only our smaller stations that have gone in for the experiment, but very large undertakings. I am glad Mr. Rankin has called attention to the use of a battery in conjunction with alternating-current supply, as it is likely to be very useful in this direction. We used to have direct current only, and thought it was the only supply to use, but we came to alternating-current supplies, and with their development we still have the direct-current systems to deal with; and if those for lighting and traction are both to be supplied from the same alternating-current generators, any arrangement to assist in maintaining a steady voltage cannot help being of assistance. The same applies in stations using motor-generators on direct current enabling the two supplies to be given by the one generator, and a short experience I have had of the virtues of a storage battery with an "Entz" booster has certainly been quite satisfactory in this direction, added to which the benefit of having a battery to fall back on in case of steam trouble I have quite recently found to be worth consideration. Mr. Atchison.

Mr. H. C. Crews: It may be of some little interest to state that I have had satisfactory results for several years with a small Lancashire reversible booster. This is used in conjunction with three 36-k.w. steam sets and a secondary battery. My scheme embraced a number of rather heavy electric lifts and a few motors, but as the load to be dealt with was mainly a lighting one, 230 volts pressure was adopted. The objects in adopting this reversible booster were: (1) To charge battery during periods of light load without using regulating cells and their bulky accessories, and (2) to keep lighting volts steady should a number of lifts and motors be started simultaneously. No. 2 provision was, of course, more particularly necessary at times when only one small set was in use. This booster successfully and quickly accomplished these objects. Testing by continuously starting and stopping three large lifts simultaneously, with maximum out-of-balance loads, the greatest variation of line pressure recorded is 5 volts. On the 230-volt glow lamps in use this difference is practically imperceptible. Mr. Crews.

Discussion before the Scottish Local Section, 9th January, 1912.

Mr. W. W. Lackie: The only point on which I do not see eye to eye with Mr. Rankin is in connection with the statement on page 285, where Mr. Lackie.

Mr. Lackie. he says that a saving in coal consumption of between 20 and 30 per cent. can be obtained through the installation of battery and booster plant, in cases where the load is of a very highly fluctuating nature, and from 10 to 15 per cent. in other cases. I take it that he bases this statement on the facts given in the last few pages of his paper. If we look at page 329 it will be seen there that when two generators are run giving 61 k.w. the steam consumption per kilowatt-hour is given as 60·43 lbs., whereas when one generator with battery and booster was run, the steam consumption fell to 43·25 lbs. It appears to me that it would pay in this particular case to shut down both generators and buy one good up-to-date generator and so get a steam consumption of the order of 25 to 30 lbs. per kilowatt-hour. I do not know what the coal consumption is at Greenock to-day, but I believe it is something better than 5 lbs. The reduction from 6¼ to 5 lbs. was partly due to improved methods of firing, as well as to the putting down of a battery and booster. I believe that Mr. Rankin has also in his mind the economy said to be due to the use of a battery in Manchester. I would like to point out, however, that without the installation of a battery or reversible booster the coal consumption in the Glasgow stations has been reduced 16 per cent. in one year. In the tramways department power house, where there is a fluctuating load, I am pretty certain that the installation of a battery and booster would not reduce their coal consumption by 1 per cent. At Pinkston last year they were generating 1 k.w.-hour of electrical energy with engines taking 18 lbs. of steam per kilowatt-hour for 2·8 lbs. of coal, which is within a small percentage of the possible theoretical figure. The theoretical figure is frequently got, but is upset due to banked boilers in the early morning hours. I agree, of course, that a battery and booster are of very great value in keeping a steady voltage, and this one cannot put a price on ; but, on the other hand, the cost of the battery and booster must always remain a small proportion of the capital expenditure on plant. Batteries will probably cost £23 to £24 per kilowatt, while steam plant costs about £12 per kilowatt. The influence of this on the selling price of electrical energy would be that with the price at 1½d. per unit, 1d. represents interest and sinking fund, and therefore if the capital cost of the plant were doubled, the price of energy would need to be increased proportionately, while there might be a reduction of 10 or 12 per cent. on the ½d. I would like to know what proportion of the total plant Mr. Rankin thinks should be in the form of batteries. We have Tirrill regulators on our alternators and these give us a perfectly steady voltage. We do not have boosters on our batteries.

Mr. Downie. Mr. F. H. Downie : I would like to point out to Mr. Rankin that in the later forms of the Highfield booster the diverter resistance for the series field coils is divided into two parts, one of which is placed in the generator circuit, and the other in the load circuit. The battery connection is made to the junction of these two resistances. The object of this arrangement is to overcome the sluggishness of the booster. Till the battery begins to discharge, the excess of load current flows through

both parts of the diverter resistance and therefore gives a much larger difference of potential across the booster series coils than is normally required to give the desired boost in the discharge connection. The result is that the current in the booster field coils changes much more quickly and the booster is rendered less sluggish in responding to load fluctuations. The steady boost due to the resistance in the generator circuit is neutralised by altering the exciter voltage. I would also like to point out with regard to Mr. Rankin's remark about flywheel equalising plant at the Gary Steel Works, that there is no proper flywheel equalising plant. The flywheels are fitted on induction motors which have permanent slip resistances, and only serve to reduce the load peaks. Mr. Downie

Mr. A. H. KELSALL: I should like to ask what booster was in use in the arrangement shown in Fig. 8, which failed so completely to get a response from the battery with an over-compounded generator. I should also like to suggest a point to Mr. Rankin with regard to the amount of copper on the field coils of boosters in Class A. The only real feature about the amount of copper is the cost of it, because on all kinds of boosters on this principle, it is necessary to work very low down on the characteristic, and that means that the standard magnet frame used has got a great deal of space upon it, and the net loss to the purchaser is the cost of copper, and possibly, say, 1 per cent., due to the extra field losses, which are a small fraction of the total losses. I did not quite catch the confidential information Mr. Rankin gave us regarding the circuit breakers in conjunction with the rolling mill installations. Mr. Kelsall.

DISCUSSION BEFORE THE BIRMINGHAM LOCAL SECTION ON 14TH FEBRUARY, 1912.

Mr. A. M. TAYLOR: I am not quite convinced that the way in which automatic reversible boosters are worked is necessarily the best for central stations or possibly for many other situations. Unfortunately for the battery it is not at present a strictly reversible machine, nor will it be until it is suited for the same rate of charge and discharge. For instance, say there was a momentary demand for 2,000 amperes for a minute: it was not possible to put the 2,000 amperes back in the following minute, but it was desirable in the interests of the battery that this should be done in not less than 3 or 5 minutes. I am not clear that it would not be more in the interests of the battery if arrangements were made whereby extremely severe "short-time" discharges could be taken out of the battery without any attempt to repay this in the form of a charge at a high rate. To attempt to repay this results in it being necessary to employ a very large booster, and the more severe the discharge the larger does the boost (rapidly) become. The automatic booster is undoubtedly a very valuable piece of apparatus, particularly because it deals with the battery as a whole and so avoids any disturbing cause tending Mr. Taylor.

Mr. Taylor. to make one cell behave differently from another. I understand, however, that on the Continent and in America automatic means have been employed, using regulating cells exclusively for the discharges, and I think that there is a danger of such means entering into serious competition with boosters in this country if size and cost of the latter are not kept in check. In my opinion this result could be obtained by sacrificing to some extent the feature of the automatic booster whereby the battery is charged in intervals between the discharges; but in this sense it would be in no way at a disadvantage compared with the matter of regulating cells, since these would also suffer from the same weakness. I am not at all convinced that the making up of a load at the generating station in this way is of such great importance, and believe that the disadvantage would be more than compensated by the greater capacity of the battery to deal with severe discharges, which would be obtained by the method I propose. Briefly this is to increase the number of cells in the battery above that required merely to float upon the line and to employ series-parallel grouping of the boosters for the purpose of putting the final charge into the battery late at night or early in the morning. In those cases where the average load does not possess a constant value throughout the whole day, but is rather of the nature indicated, for instance, by the curve given by Mr. Turnbull in his paper on the subject,* there would be a very decided gain in employing series-parallel arrangements. In Fig. C let A A represent the voltage per cell obtained by dividing the busbar volts by the total number of cells of the battery (which in present practice usually works about 2·12 volts per cell as shown). Suppose, for example, that the busbar volts are 550 and there are 260 cells. The curve D E would represent the gradual fall of potential through the battery during the day if the load consisted of a number of current impulses at the 1-hour rate with considerable gaps between them, but occurring uniformly throughout the whole day. The curve F G represents the charging voltage at the 4-hour rate, and supposing that at the commencement of the day the volts per cell were 2·5, it would be obvious that for the first 3 or 4 hours it would be impracticable to put any charge into the battery, and as the battery got more and more exhausted it would receive a charge more readily as shown by the fall in the time H F. If J K represents the curve of discharge for a ½-hour rate it will be seen that if the booster was put in to give a boost for the limit of the 1-hour rate that booster would be quite incapable of getting the ½-hour rate out of the battery without the expenditure of a large sum on the booster. The booster would in the early morning have to give a boost of 82 volts (1-hour rate), and in the evening of 115 volts, or a mean boost of approximately 100 volts. No doubt this would give ample facilities for the charging of the battery, but this amount would be entirely unnecessary, the actual boost required to charge the battery at the point H being only 47 volts, and at the point L only 20 volts.

* *Proceedings of the Institution of Electrical Engineers*, vol. 36, p. 591, 1906.

Mr. Taylor.

Suppose that the 1-hour rate of the battery corresponded with 2,000 amperes, then the average output of the booster would approximately be 200 k.w. If the number of cells were increased to 285, giving the line B B for the busbar voltage at 1·93 volts per cell, the boost for the 1-hour rate early in the morning would be only 37 volts, and towards the evening 75 volts, an average of 56 volts, which would reduce the size of the booster to very nearly half the size of the previous case. This would enable a light charge to be given to the battery early in the day, and when the point L was reached on the charging curve the full charge could be put in (4-hour rate). If, however, there were any valleys in the load curve for any period of time such as given in Mr. Turnbull's curve already referred to, and if the booster could be arranged to be coupled in series or parallel at will it would be quite

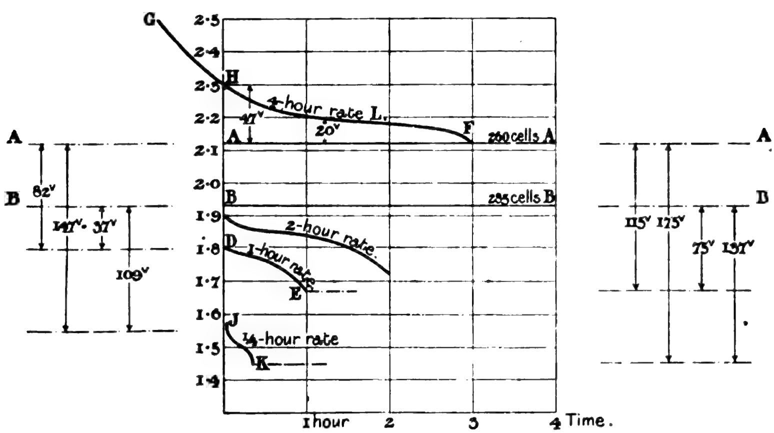


FIG. C.

feasible to give any charge required by the battery at any time of the day. I have worked out a switching arrangement which could be operated without any adjustment of the booster field or interruption of the current. Another way of putting the case would be to say that with the same booster as first contemplated (200 k.w.) it would, with series-parallel control and the increased number of battery cells, be practicable to give discharges down to the ½-hour rate as shown by the curve J K. It may be argued against the above proposal that an increased number of cells has to be put into the battery, but it would be found that owing to the reduction in the amount of boost required and the size of the booster the current taken from the battery to drive the booster is so much less than before that the reduction in the output of each cell throughout the whole battery is sufficient to pay the capital value for the increased number of cells, while the energy losses in the boosters must obviously be less with the smaller booster,

Mr. Taylor. and the general efficiency is improved. At certain parts of the day the booster would be called upon to "back-boost," that is, to "motor"; but this would be in itself no disadvantage.

Mr. Forster. Mr. F. W. FORSTER: On page 285 of the paper the author states that in the case of a works generating its own electricity for lighting and for a very highly fluctuating power load, the economy shown by a battery booster attains its maximum. I do not agree with this and previous remarks in so far as it is intended to show that an automatic reversible battery booster plant is of greater advantage in a works than in a central station for the reason that the load factor in most works where a battery booster plant would be proposed is better over the working hours than over the working hours of a central station, which are in the latter case 24 hours to the day, and include many periods of light load. The disastrous effect of bad voltage in a particular works mentioned by the author on that page is probably due to badly chosen plant, and as far as the paper showed this could be as well corrected by suitably compounded or regulated machines as by a battery booster plant. The disadvantage of over-compounding a generator and booster mentioned on page 295 is best corrected by altering the compounding of the generator to level compounding by means of a diverter or definite alterations of the series turns on the generators, for I am of the opinion that it is inadvisable to use over-compounded generators with over-compounded boosters, and believe that general opinion now advises level compounding of the generators or even plain shunt winding at stations of moderate or large capacity. If a battery booster plant is installed for the purpose of equalising the load on the station, then the remarks attributed to Mr. G. A. Grindle must be accepted. The engine was run on the stop valve and adjustments of load made by hand-regulated cut-offs. The sluggishness of the inductive leg of the diverter circuits in obtaining relative values could surely be overcome by using tappings on the series coils and a selector switch if the inaccurate working mentioned by the author on page 299 is worth serious consideration. I should be glad if the author would give some details as to the capacity of the boosters mentioned on page 326, and which I understand took up the peaks shown in Fig. 25. As the author had claimed traction and similar loads as within the legitimate field covered by battery booster plant, I might point out the great advantage of end cell regulating gear as used on the Continent. Those were automatic in action and result in much higher economy; they are lower in first cost, more robust, and less liable to damage when short-circuit conditions arise.

Dr. Garrard. Dr. C. C. GARRARD: With regard to the author's remarks *re* the sluggishness introduced, due to the fact that the diverter is non-inductive while the field coil in parallel with it is highly inductive, I would like to ask whether this could not be got over by making the diverter inductive. With reference to the split-pole converter mentioned on page 322, the simplest way of looking at the action of this machine is to regard it as a question of distortion of E.M.F. wave-form. The direct-

current voltage of a converter is given by the maximum value of the E.M.F. wave, while the alternating-current value is given by the R.M.S. value of the wave. By splitting the pole-face, the wave-form is distorted so that the relation between the maximum and R.M.S. values could be altered. The over-shooting effect mentioned on page 303 in connection with the Entz booster is of great importance, not only in connection with that type, but also with the Tirrill regulator. It is rather extraordinary at first sight that either of these regulators should act with the rapidity with which they do. To me this rapidity of action seemed to depend upon this over-shooting principle, viz., the initial change in field excitation voltage is made much greater than is actually required to take charge of the alteration in the load. Directly, however, the required regulation is obtained, the action is suddenly stopped and an over-regulation is prevented. The author shows clearly the principle in the curves on page 304, and as explanations of the actions of these regulators are not generally available, the paper is the more valuable for dealing with this point so excellently. Dr. Garrard.

Mr. R. Rankin (*in reply*): I hope the battery makers will take note of Mr. Highfield's criticism of maintenance agreements. I agree with him as to the inadvisability of working a battery on the extreme end of the charge curve, but it is sometimes necessary to work there, Fig. 8 illustrating a case in point, where the battery supplies early morning cars. Even with the battery in a comparatively low state a load with large dips below the mean will show the effect referred to. Some of the external regulators are much quicker in action than the Thury; the degree of quickness of the latter is referred to in the remarks made by Dr. Morris and quoted in the paper. I am afraid that the construction of an inductive diverter for a booster would not be such a simple matter as Mr. Highfield thinks; the iron core would probably be rather a massive affair, and would mean additional expense on the very type of booster that cannot bear it. A flywheel is an advantage on a diverter booster, but where an external regulator is employed a little slowing up of the motor is automatically compensated for by a little more booster field current. Such boosters can be run at very high speeds with consequent diminution of the amount of material in them and cost to buyers. So far as compounding of the main generator is concerned, I agree with Mr. Highfield; if the booster will equalise properly there is usually no reason why the generator should not be run shunt. A constant station voltage is usually considered good enough for tramway purposes, provided it is accompanied with a steady generator load. Mr. Taylor deals with the question more from the point of view of the battery itself, and that when used with hand-regulated boosters, and this is rather outside the scope of the paper. The 10 to 15 per cent. savings were obtained in a corporation station with a fairly stiff traction load. Of course, usually, the larger the mean traction load the less is the need for equalisation, due to the influence of diversity factor. I have, in fact, seen an industrial load of at least 2,000 amperes on the average, which did not vary more than about 200 amperes from that Mr. Rankin.

Mr. Rankin. mean, although almost entirely a motor load. The only disturbing factor was a flywheel equalising set, and, when this started to equalise, peaks of another 2,000 amperes or so were the result. This may be interesting to Mr. Scott in connection with his remarks concerning the Rothesay Docks plant. In cases where the battery has to be tied absolutely across the busbars in emergency, and it is desirable to short circuit the booster, the booster field must be broken at the same time. I have had this arranged for in one instance where the arrangement works very well. The booster short-circuiting switch is hand-operated in this case. Battery makers should have a large say in the controversy between the advocates of cell-regulating switches and hand-regulated boosters; they complain bitterly about the treatment the regulating cells come in for. It is not likely that the savings effected by installing a Tirrill regulator for the purpose of keeping a constant voltage would anything like pay for a battery, but it might well have been that the installation of a battery, properly controlled for load equalisation, would soon have paid for itself. As Mr. Taylor says, it is a good way of utilising a battery on an alternating-current system to charge it by means of a synchronous motor-generator, the synchronous machine being also used, in conjunction with a suitable regulator or exciter, to improve the power factor of the main load. Replying to Mr. Burge, the action of the simple Pirani booster is dealt with, in the part of the paper he refers to, without limiting devices. Limiting devices are referred to on page 290. I cannot imagine that the action of such a booster can be made satisfactory by an adjustment of brush position; no greater proof, I think, is necessary than the fact that there are so many limiting devices of the kind named. I have simply given one; Mr. Worrall, in the discussion at Manchester, refers to others. The rise of current in the booster armature may be a great deal more rapid than that in coils A and B, but cannot occur until A and B act. Applying this argument to the armature of the main generator, is not the rise in current here also likely to be more rapid than that in A and B, and hence than that in the booster armature? That extra sluggishness is not introduced by some of the other systems of boosting described is shown by charts such as those given in Fig. 27. I shall refer to results obtained by conversion of diverter boosters into externally regulated ones later on. The action of the coil D, and the benefit derived from its employment, are fully described in the paper. Fig. 18 represents a scheme actually put forward by Messrs. Crompton & Co.,* and I should judge that, although a less number of machines were employed, the principle remaining the same, the method of making the battery work would give rather poor results. The figure of 10 per cent. load regulation either side of the normal certainly is better than I would expect. Mr. Jenkin confirms the point raised about time lag in diverter boosters, and his experience is all the more striking as giving point to my arguments because working with motor-generator plant is the most favourable condition for a battery and

* *Electrician (Industrial Supplement)*, vol. 64, p. 154, 1910.

Mr. Rankin.

booster. Fortunately, as he explains, the motor-generators were able to take care of themselves in spite of the defective working of the booster. I may here say that the effect of lamination of booster fields is very much over-estimated. It cannot affect hysteresis lag, and the lag produced by eddy currents, acting in accordance with Lenz's law, is only a small percentage of the total. The best plan is not to try and

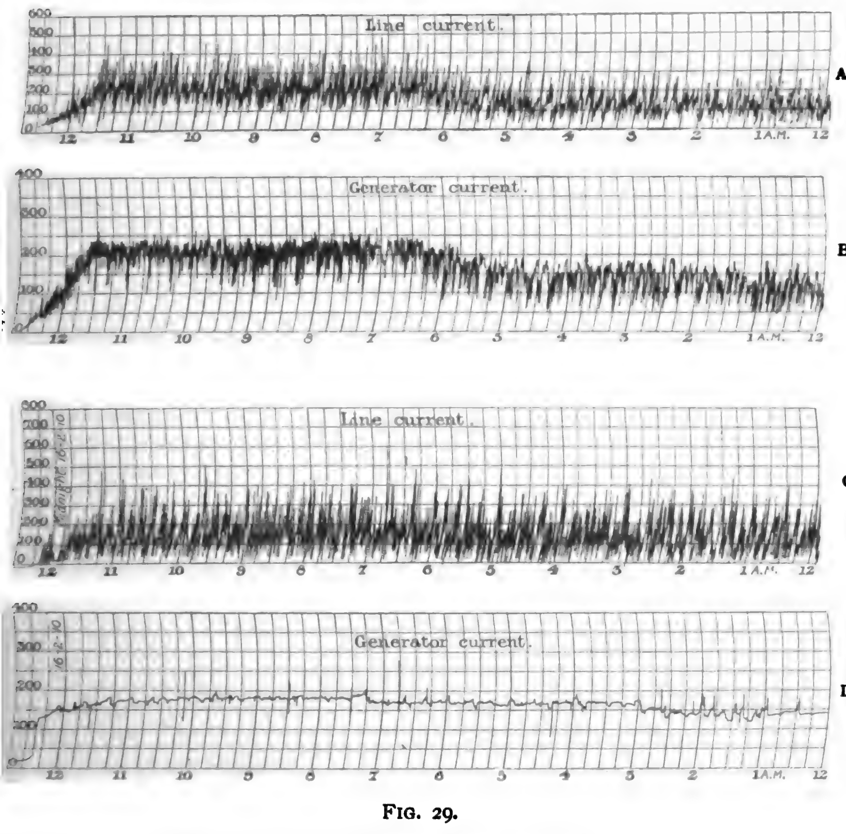


FIG. 29.

Charts A and B taken with diverter booster working.
Charts C and D taken with above booster converted to Entz control.

reduce the time constant by costly design, but to use a system of control that will rapidly overcome it. I regret that I cannot give any figures as to the difference in actual time-lag in diverter and externally regulated boosters, but the results obtained in practice as regards equalisation of load speak for themselves. Using the equation on page 300 in the case of a Highfield booster with straight-line diverter I have calculated the rate of rise in current in the diverter to be, initially,

Mr. Rankin. 200 times that in the diverter field-coil. When this is borne in mind and Fig. 10 considered, a fair notion of the different actions may be obtained. A chart shown later (C, D in Fig. 29) emphasises the improved results obtained by means of external regulators. This should settle any doubts Mr. Jenkin may have about the efficacy of the latter as compared with diverters. With regard to relative costs, the following are respectively approximate prices of a laminated field diverter booster, an Entz, and an unlaminated field Highfield booster quoted for one installation, all to give the same outputs, £750, £560, £575; the switchboard prices being respectively £178, £180, £190, exclusive of cable connections, which would be much less for the Entz than for any of the others. Of course the ratio of prices would not hold in all cases. Compounding of the main generator as described by Mr. Jenkin is mentioned in the paper.

In reply to Mr. Allingham, there are very many types of automatic boosters besides those described, but I think I have chosen representative ones. I may here mention that I had much difficulty in obtaining particulars of some systems, which may account for the fact that some of my diagrams do not quite please Mr. Allingham, but I am tolerably certain I have shown the principles involved in the figures. To take the Tirrill regulator, which he specially refers to, it would require a bulky paper to describe all the modifications of the scheme shown in the paper, but the root principle is the same all through. He objects to the names by which I have called some of the systems, but does not suggest others. The object of the paper is that stated at the beginning, and I think that no one type of booster has been unduly favoured or condemned. The records illustrating the paper were the best that could be obtained from the systems concerned. There can be no objection to Mr. Allingham's classifying boosters in the way he mentions. I should be very happy myself if all those described by him as working imperfectly were recognised as inferior—or, in fact, discarded—and only the Lancashire and externally regulated systems left, although the defects of the former due to its inherent sluggishness would inevitably show up by comparison. The imperfect boosters do not give a boost proportional to the line current, as in all cases the effect of the generator current is more or less neutralised in some way; and, where the generator current is about as large as the value of the peaks, the boost cannot be even approximately proportional to the line current. Some of them may, however, give a boost in excess of that required to give the correct battery current. Mr. Allingham's "Ulysses and the Tortoise" series is incorrect, for he calculates the voltage made available by a diminution of shunt field strength on the increase in the effect of the series coil, which is obviously wrong. Surely even what he gives may fairly be called a building-up effect. The statement taken exception to on page 289 of the paper is too emphatic, but is modified by both preceding and following clauses, which say that the battery "tends" to take the whole load off the generator. There is no question as to the effect of the third coil on such a booster. I may

Mr. Rankin.

say that I recently saw a 2-coil Pirani booster which was cited by representative of the makers as a sample installation, and, with the best adjustment that could be obtained, the variation in line voltage—nominally 550 volts—was from 490 to considerably more than 550 volts. Presumably the rendering of the characteristic curve of the booster unsymmetrical on the two sides of zero in the Pirani booster is to limit the action I described, although Mr. Allingham does not call it instability. If R_1 and R_2 (Fig. 4) are unequal, a single resistance in the exciter circuit would not serve the same purpose. I have already pointed out that none of the boosters—not even the Highfield—is controlled by the line current. Mr. Allingham's own description of the working of the 3-coil booster proves it, for he points out that, neglecting saturation, there is no limit to the increase of booster voltage; this would imply that similarly there is no limit to the line current, if it were true that the boost were proportional to the line current. It is a fact, however, that—owing, perhaps, to the action of Highfield exciter and diverter being separately described—the action of the line diverter has not been sufficiently emphasised in this case, the E.C.C. booster, as classed with the Highfield, also escaping special comment. Highfield boosters, as shown in Fig. 6, are made to work, as Mr. Allingham has pointed out, by a judicious relative adjustment of the effect of the shunt and diverter coils. Moreover, Mr. Downie has pointed out what I have not mentioned—that this feature of the Highfield booster has been observed and dealt with in practice by those concerned in the Highfield booster. The working of the Lancashire booster, as described in the paper, is exactly as given by Mr. Allingham, but I have mentioned the weak as well as the strong points of the system, and that is where I differ from Mr. Allingham. The chart of generator current obtained with a Lancashire booster, and shown in Fig. 28, is the best I could get. I am rather at a loss to know wherein lies the complexity of the external connections for the Entz booster. Entz regulators have a fairly high resistance and have been built, and are in use, for direct connection across a 600-volt battery; but smaller regulators are usually employed for purposes of standardisation. With the commonest size, tappings are taken off at intervals of 25 to 30 cells, giving normally 100 to 120 volts across the regulator, the size of wire being 7/22's. It surprises me to hear an engineer talking in such a way about small wires "constantly alive" in the battery-room. Is not the battery constantly alive and uninsulated? Are not the few wires he mentions insulated and properly coated with acid-proof paint? True, they are "live" all the same—behind the insulation. One of the selector switches for the wiring referred to is changed over daily—surely no great task for the attendant. The advantages of the Entz booster, such as absence of moving contacts, etc., are mentioned, but not unduly extolled in the paper—certainly not more than they deserve. As regards Fig. 13, this is quite correct, being a diagram for an installation actually quoted for. It is not stated in the paper that the regulator would reverse the booster voltage; its function is quite different, as an

Mr. Rankin. intelligent study of the figure and description will show. The limit stops E and F (Fig. 9) serve their purpose very well in practice, as the charts C, D in Fig. 29 show, and the difference between the "before" and "after" charts show that overshooting is not prevented. I do not at all see how regulator tappings can give the same results on a diverter booster as E and F give here. A pair of records shown in Fig. 30 are taken from a Lancashire booster, and show that "patient adjustment on site" is not so unnecessary as Mr. Allingham tries to make it appear. The adjustment here was carried out over several years. Even the chart illustrating the paper read by Mr. Turnbull, and reproduced in Fig. 28, does not show anything to be enthusiastic about. In connection with the Hucknall installation, an experiment with the proper type of apparatus would certainly have been a successful one; but where doubt existed as to the apparatus, it was wisest to stick to something that had already been tried.

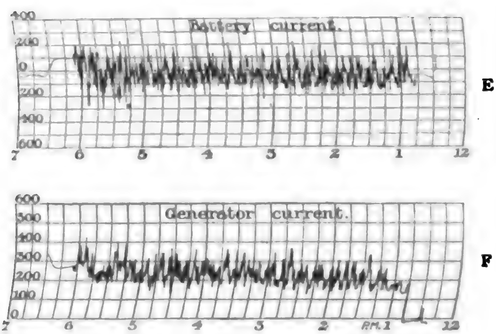


FIG. 30.—Traction System.

Charts E and F taken with Lancashire booster working.

I do not think the plain differential booster can be said to work very well, although it must, of necessity, knock off a portion of the peaks in the load; the best booster is surely that which does this to the greatest degree, and that is not the plain differential. The provision of a motor-driven accumulator switch for the purpose of regulating the speed of hoist motors would be out of the question. Fig. 19 in the paper shows one way of dealing with this type of load, which would give better equalisation of load than a flywheel scheme, and which is surely not more complicated than the method of obtaining a good voltage described by Mr. Scott. For the control of flywheel equalisers where these are to be used, I consider that nothing could be better than one of the quick-acting regulators described in the paper. Mr. Scott is quite correct in his statements about the long lives of carbon resistances. As regards the homopolar dynamo, I see no reason why this, if it can give as good results as those of the ordinary type, and is cheaper, should not be used in booster work. Mr.

Mr. Rankin.

Mordey's remarks are of interest as showing the origin of the carbon type of variable resistance and some of its applications, and I think that the Entz carbon regulator is, when the method of controlling the exciter field is considered, one of the most ingenious and useful of those. Regarding Mr. Hopkins' comment on flywheels, I had, of course, no intention of advocating the abolishment of engine flywheels. The effect of those is to hold the generator up to its speed, and thus to any demand for extra load that may fall upon it. This action means, of course, that although the engine and dynamo take part of the increasing load, some of the stored energy in the flywheel is used up.

Mr. Siddeley's remark concerning diverter design and the reaction of field self-induction is not correct, but I think I have done the Lancashire booster every justice. It is the best of its type. Unless the design of the magnetic circuit itself is modified, nothing can be gained by juggling with the number of diverter coil turns. The number of ampere-turns is settled without reference to the number of turns or the current in them. With a given winding space, doubling the cross-sectional area of the turn halves the number of turns, and reduces the inductance to a quarter of the initial, but halving the number of turns and doubling the area also reduces the resistance to a quarter of the initial; hence the time constant, and therefore the rate of building up, remains unaltered. The higher voltage due to compounding of the main generators and its consequent effect on coils B and A must be in evidence before the motor speeds up, and, although the speeding up of the motor, such as it will be, will tend to overshunt coil D, the initial increase in generator current will doubtless occur. This action of overshunting would only be beneficial if D were giving a discharge voltage, but, as it is a fact that, depending on the state of the battery and number of cells, the booster may have to back-boost, the over-shunting action may actually assist the over-compounding of the generator. In any case Mr. Siddeley is wrong in saying that this type of booster is the best for working with compound generators; with externally regulated sets generator voltage practically does not enter into the question. Regarding Fig. 8, this is quite a representative one for the conditions. I suppose Mr. Siddeley means that it is not an ideal one, and to that I will agree. If an engineer wants a full battery for early morning cars, as in this instance, why should he not leave off with his battery in a full state of charge? Of course running with the battery fully charged at unnecessary times would be foolish, but I consider that the best point at which to operate a battery is that at which its voltage when idle is approximately equal to that of the bus-bars, and, therefore, can see no point in Mr. Siddeley's statement that no booster will regulate well under those conditions, unless that it is that the Lancashire booster, depending so much as it does on its self-excited shunt coil, works worst with the battery in the best condition. His reasons are really arguments in favour of an externally controlled booster.

It is surely useless to say that, when an exciter is used in connection

Mr. Rankin. with a diverter booster there is no extra lag involved; the booster voltage must inevitably lag behind that of the exciter. I believe the Manchester Corporation boosters are but little used automatically on traction, and am certain that when they are, the load regulation cannot be very close. I agree as to the advantage of having a system without anything that can stick, but there are external regulators—the Entz, for example—on which there is nothing that can stick more readily than, say, the motor armature. Figs. 29 and 30 have already been referred to. The former shows line and generator currents on a traction system employing a diverter booster with laminated field before and after conversion to Entz control. No comment is necessary, except that the bottom chart shows, very clearly, the effect of the lever stops on the Entz regulator in throwing the excessive peaks in the load back on the main generator. Fig. 30 shows the results obtained from the employment of another type of diverter-booster with laminated field, the chart of line current, however, not being available for reproduction. All the records exhibited in Figs. 27, 29, and 30 were taken by the same instruments.

With reference to Mr. McKinnon's remarks, I think that the day when the use of battery-regulating switches was considered possible with highly fluctuating loads is past, so far as this country is concerned. There was little need for that Continental engineer's surprise; it would have been surprising to find many such plants working. Mr. Atchison dealt with one aspect of Mr. McKinnon's point as regards its sometimes being cheaper to leave the booster standing than running. I am afraid Mr. Cooper is still in the gall of bitterness, so far as the use of batteries is concerned. With regard to Greenock, I would refer him to page 330, where it is stated that the battery at Greenock was not on maintenance, and was in use for six years before any money was spent on it at all. This shows that battery maintenance did not explain the difference in figures of repairs and maintenance cost which he refers to. Local circumstances and difference in type of load might make Mr. Cooper's costs less than those of some other given place. This is, however, not the question. The question is, "Are Mr. Cooper's costs as low as they might be?" and a thorough consideration of this question might pay him well. Mr. Wheelwright's remarks should interest Mr. Cooper, giving him just the sort of information he asked for, and bearing out the views which I have put forward in the paper. In reply to Mr. Worrall, I may say that it is a rather difficult matter to obtain reliable charts showing the results obtained from different systems, and any other kind would be out of place. All the recorder charts illustrating the paper and my reply to the discussion, with the exception of Figs. 8 and 28, were obtained by myself, and with the same instruments throughout. I could not obtain a Pirani booster chart, so I used the figures in Table I. I had an Entz booster chart in Fig. 27, and did not require another to go with Table II. Table I. should not be compared with Table II., but with Figs. 27 and 28. As regards Fig. 28, I considered that I could not go wrong in taking the figure illustrating Mr. Turnbull's

Mr. Rankin.

paper, which dealt entirely with the Lancashire booster, and believe that this shows the best results obtainable with this booster. Mr. Worrall is perhaps justified in his remark in connection with the instability of line diverter boosters, but Fig. 8 shows I have not made too much of the effect of over-compounding. His description of the Pirani modifications disposes of the argument put forward in a previous discussion that such modifications are entirely unnecessary. The short description given of the Elmira plant is interesting, but I consider that external regulators, with the overshooting property described in the paper, the most satisfactory for alternating-current work as being quicker in action. In connection with my remarks *re* the Gary plant, I am surprised that nothing has been said about the question of flywheels *versus* batteries. It would have been interesting to hear the views of some of the advocates of the former. Mr. Frith seems to agree with me entirely with regard to the sluggishness of diverter boosters, and his statements should be carefully weighed by the advocates of diverter systems. He emphasises the points which I have tried to bring out clearly in the paper, particularly in the equation on page 300, *re* the relative rates of rise in current in diverter and diverter coil. Highly inductive diverters would be expensive. The lamination of the field of a diverter booster is an expensive matter, and additional cost would be a great disadvantage. The iron core in the diverter coil itself is fairly massive, being the magnets of the machine. Some engineers have the notion that fields cannot be reversed quickly unless they are laminated, and are prepared to pay for this, but this is quite a mistake. In reply to Mr. Stewart, the Entz booster is certainly the simplest on the market, as is borne out by Mr. Wheelwright's remarks. Evidently Mr. Stewart has not understood its action. Control is effected solely by one adjustment, which is purely mechanical, being simply the turning of a small hand-wheel. I do not question the excellence of the electrical and mechanical design of the machines forming Mr. Stewart's booster, which are all that are concerned in its long period of running; there are many machines working for long periods without giving trouble. Mr. Stewart's main generators also seem to be well designed, as, in spite of a variable load, a straight-line voltage chart is obtained. A reversible booster should not be concerned with the generator voltage, and I have tried to show that externally regulated boosters are not, but they should be capable of maintaining a steady generator current. This, although Mr. Stewart says he does not want it, is precisely what engineers have in view when they install a battery-booster plant. Of course, if the fluctuations are more than the battery can do, the defective working of the booster will prevent it from being over-worked, but this is a poor argument in favour of the booster. There is mention made in the paper of the fact that the installation of a sluggish booster may keep down initial cost, as, since the booster will not make the battery work properly, there is little use in laying down a battery of large capacity. With, say, a booster of the Entz type, which Mr. Stewart has expressly mentioned, excessive peaks and dips could be thrown back on the

Mr. Rankin. generator, and the best equalisation still obtained for all normal peaks. That Mr. Stewart's booster is not remarkably quick in acting is shown by the fact that he does not get a steady load on his generator. With regard to lighting consumers on traction systems, the degree of their satisfaction is very often a matter of education. His last remark confirms my statement that batteries working with reversible boosters remain in very good condition indeed provided they receive reasonable attention. Mr. Wilkinson's account of the working of a regulating switch at Zurich on a tramway load helps to explain why this type of thing is not taken up in this country. He asks why alternating-current regulation has not been taken up in this country. I have been looking for a satisfactory reason for this for a long time, but have not found it. There are certainly not so many openings here for this type of plant as there seem to be in America. I think I have given one of the main reasons in the paper when I said it is due to conservativeness. As Mr. Atchison says, diverter boosters, which cannot be described as quick-acting, have a sphere of operation, but that is where they should be employed, provided their cost is right; but simplicity in operation is a thing which should be considered. Nothing but dissatisfaction can result from their employment on quickly varying loads. I am glad to hear Mr. Atchison say that he has made a decided gain by having a steady traction voltage. Many engineers make a great point of their not being able to compound on traction with a steady generator current, but provided an externally regulated booster is used, there is no reason why the feeder current should not be carried round the generator field, and compounding, if desired, obtained in this way. Of course, as the regulator will keep a steady current on the generator, the load on the engine will go up in proportion to the voltage. I commend Mr. Atchison's remarks as well as Mr. Wheelwright's to the notice of Mr. Cooper. With reference to Mr. Crews' remarks, it is likely that on a small installation like the one he referred to the generating plant is big enough to deal with the fluctuations itself, the battery and booster being merely a refinement, the former being required more for periods when the generating plant is shut down than for equalising. In the steel works mentioned in the "Practical Results" section of the paper, where the motor load consists of charging machines, cranes, etc., and the voltage is 220, the variation in voltage with the battery and booster in use is less than 3 volts on an indicating, not a recording, meter. The generators have a drooping characteristic, and the magnitude and rapidity of the variations in line load are a great deal more trying than those on a traction system.

I am afraid that the particulars I have given of the plant referred to in connection with Table II. have not been complete enough, or Mr. Lackie would not have got such a bad impression of the engines and generators. Those would require to be very good indeed to get a steam consumption of 25 to 30 lbs. per kilowatt-hour if the rated output were only 60 k.w. As a matter of fact, the rating of each generator is 172 k.w., and the fact that two of them had to be run on a mean load of

Mr. Rankin.

about 61 k.w. shows that the load with which they had to deal had fluctuations of an extraordinary nature. While the two generators were running alone the lighting load had the effect of raising the average output, but the peaks due to the large motors still existed, with the result that the two sets were running very inefficiently. In fact, it will be seen that, even with one generator running, the average load is very low, but, as pointed out, extensions were made after the tests, which have increased the average load, and the saving is now more than that shown in the table. If the original power and lighting scheme had allowed for a battery and booster the plant could have been made to suit the load to a very much greater degree than is indicated by the particulars I have given. The main point is that there are many plants in the country of a like nature to that described, where steam plant has been put in to handle the entire load, including the peaks which are of very short duration, although extremely frequent, and that even although after a battery and booster had been installed the steam consumption would not be reduced to the minimum because of the unnecessarily large ratings of the generators, still the economy effected would be on such a scale as to pay for the introduction of the equalising plant and a steady voltage, and reduced wear and tear would be additional advantages gained. In the installation referred to meal-hour and week-end loads are taken by the battery, and it must be pointed out that one of the generating sets is now a spare instead of a necessity—this over and above the economy effected. Previously there was no spare. It appears to me that but little can be said regarding rather out-of-date plant in works—although the plant in the works referred to is quite up-to-date—since, even in such an up-to-date installation as that of Glasgow Corporation, a saving of 16 per cent. in coal consumption was actually made in one year without the aid of an equalising agent, and therefore presumably by improved plant or methods. By all means let us have improved stoking, but let us not throw away the advantage to be gained from the use of a good equalising plant. I believe the reduction in coal consumption from 6¼ to 5 lbs. per unit at Greenock was due entirely to the equalising plant; any further reductions may have been due to improved methods of firing. It should be observed that in works such as those mentioned in connection with Table II. the effect of diversity factor is inconsiderable, and in this the load differs from that on such a large tramway undertaking as the Glasgow one; the load fluctuations are very large and exceedingly quick. I myself have seen very large loads which needed no equalising agent, and the installation of a battery and booster to obtain not a steady load but a steady voltage is out of the question on the score of cost. A voltage regulator without a battery is all that is required.

Mr. Lackie's figures for the cost of batteries are very misleading, the cost per kilowatt of a battery varies with the rating taken, and on the 10-hour rating, say, the cost of a battery per kilowatt would be preposterously high. The figure of £24 is for about the 3-hour rating

Mr. Rankin. presumably, but it should be borne in mind that batteries working automatically can be discharged with perfect safety up to three times the 1-hour rating, say six times the 3-hour rating, reducing the above figure to £4 per kilowatt, which is available just at the very time it is required. This, of course, upsets Mr. Lackie's other figures as to cost per unit. It is quite impossible to say in general terms what proportion the capacity of the battery should bear to that of the station. If the battery is to be used as a buffer its size will simply depend on the magnitude of the load peaks and dips, and be independent of the mean load. On a load consisting of a very large number of motors those peaks and dips may be negligible in comparison with the mean and a battery not be necessary as a buffer. On the other hand, if a battery is required to act as a standby in the event of engine failure or to handle a load unassisted over a period of time, its size will be settled by a consideration of the readiness with which repairs can be carried out or other generating plant started up, and a knowledge of the load during the required period of time respectively, and of those every engineer is judge for himself. Several speakers in the discussion on the paper at Manchester are users of boosters, and their remarks in connection with savings and reliability obtained should help to convince Mr. Lackie that there is something in this type of plant for use even in central station work.

I have been concerned in the installation of some Highfield boosters, and the object of the later modifications is not to overcome inductive lag but to get over the over-compounding effect of a line diverter. Mr. Downie has been misinformed regarding the Gary Steel Works plant. The rolling-mill motors are provided with automatic regulating features, and those are described in a paper by Mr. B. R. Shover.* Fig. 8 was obtained from a Highfield booster installation. Of course, as Mr. Kelsall says, the cost of the extra copper and the loss in efficiency are the real points in connection with Class A boosters, but when those disadvantages are added to the cost of laminating the fields of those boosters and the other disadvantages they possess, the sum total is quite considerable. I mentioned a rolling-mill plant connected across the motors of a lighting system where an Entz booster is installed. Incidentally I said that the maximum demand was expected to be about 800 amperes, but that it actually was much in excess of this, the breakers being set for 1,600 amperes, and tripping continually.

It is very possible that the present methods of operating automatic boosters may be improved upon; as Mr. Taylor says, the shapes of the battery charge and discharge curves are sources of considerable trouble. It is refreshing to hear a user of batteries speak in their interest; usually they receive very little sympathy indeed. Undoubtedly it is a bad thing to try and store energy in a battery at too high a rate, and some boosters absolutely refuse to do it—see Fig. 8 in the paper—but I would point out that with some externally regulated

* *Transactions of the American Institute of Electrical Engineers*, vol. 28, part 1, p. 101, 1909.

Mr. Rankin.

boosters it is possible to limit the charging current to a desirable value, and allow the generator current to decrease, and at the same time to get a good equalising action for all normal working, and to avoid the extreme conditions with which Mr. Taylor deals at considerable length. With regard to regulating switches, what must be the state of affairs with them if so many difficulties are encountered with the use of boosters? Series paralleling of boosters as described by Mr. Taylor would be quite impracticable on just such loads as an automatic booster would be useful for, and the extra cost of cable and switch-gear required, together with the cost of the extra cells proposed, would go far in any case to counterbalance any saving obtained from a reduction in booster capacity. If the battery is to discharge on every occasion of a peak it should charge on the occasion of every dip; if it it is not allowed to charge in this way its capacity will require to be greater. Dips equivalent to the 1-hour discharge rating of the battery can be handled quite safely, the battery being operated normally at a state of about half full charge. Its voltage seldom falls to that corresponding to its being empty at the 1-hour rate. The whole question is a matter of the energy required by the station load. This is equivalent to some steady value of current at busbar pressure over the period of working, but, if an equalising battery and booster are employed, the generator requires to give a somewhat higher value of steady current than that referred to, in order to make up the losses in the equalising plant. With a given battery the booster voltage to put a definite current into it is practically equal to that required to draw the same current from it, the line voltage remaining constant, and the battery being in a good working condition. If the line demand increases above the value which the generator is set to do the battery discharges, but all the discharge is not absorbed by the increase in load; part of it goes to drive the booster motor. Similarly, if the line demand decreases the battery charges, but the entire drop is not available for the battery; part of it again goes to the motor. An increase in the number of cells would reduce the energy supplied to the booster motor on discharge, but would increase it on charge, so that no decrease could be made in motor capacity, assuming that nothing is provided to check either charge or discharge. Any decrease in the size of the battery because of the reduced power taken by the motor on discharge simply increases that taken on charge. The matter being one of the transference and re-transference of a certain amount of energy in a certain time, no reduction in plant capacity is possible. If, as Mr. Taylor suggests, the charge should be suppressed over a period the battery capacity must, as already said, be increased, and this goes to neutralise any saving effected through the booster capacity being reduced.

All the foregoing remarks are with reference to automatic plant for rapidly fluctuating loads. For lighting loads having well-defined large peaks the case is somewhat different because the charging current may in some instances be kept down to such an extent, through an extension

Mr. Rankin. of the time of charging, that the rating of the booster motor may be reduced. In present practice the maximum discharging current multiplied by its maximum voltage is usually approximately equal to the normal charging rating multiplied by the maximum charging voltage, the voltages being in the ratio of 2:1. Any increase in the number of cells would increase this ratio, and put up the charging voltage in direct proportion to the increase in the number of cells, and, therefore, for a reduction in motor capacity, the reduction in battery capacity, consequent to the increase in the number of cells, would have to be of such a magnitude as to decrease the charging current in a greater ratio. The booster capacity would be reduced by the reduction in current taken by the motor on discharge and by the paralleling of armatures, but against this has to be set the cost of extra cells, switching arrangements and cables, and the saving is problematical even in this case. If the argument for the installation of a large number of cells than that at present customary is that it enables a greater proportion of the stored energy to be used at times of heavy peak on lighting loads, it is valid, but it is very doubtful whether anything can be gained in a reduction of capital cost. It is an excellent thing to have increased available storage if the storing can conveniently be done at times of light load.

In reply to Mr. Foster, an automatic booster in an ordinary central station is only useful on traction, which is only a part of the load, and that a minor one very often. An inspection of a steel works load chart, for example, will show that what I say in the paper regarding savings is correct. The results given in Table II. are for such a load with a maximum mean load of about 600 amperes with peaks to about 1,500 or 1,600 amperes of short duration occurring rapidly one after the other during the whole period of working. Two 800-ampere generators would be required to handle the load without the battery and booster, whereas, with them, one at a maximum of about three-quarter load is sufficient, having only a steady load to handle and giving a constant voltage. The average mean load over the period of the test connected with Table II. was about 300 amperes. The other works mentioned in the paper employed gas engine-driven generators, which were probably compound, but with a load like that outlined above the compounding was of little avail. Regulating the voltage would not give the advantage of a steady load, whereas a proper battery and booster would give both steady load and voltage. With regard to the compounding of main traction generators, opinions differ as to its desirability. Altering the compounding of existing generators is not always an easy matter if it is intended to do so only when the generators are working with the battery and booster. If the right booster is used a shunt winding will do, but where the booster is sluggish this would lead to bad voltage and compounding is desirable, which, in itself, tends to allow the battery to do less work.

I do not follow Mr. Foster's remark *re* tappings on the booster diverter coil to decrease lag. If a voltage has to be produced on the

booster by the coil the turns must be there. Traction and similar loads are not only within the field covered by battery booster plant, they are the ideal loads for automatic plant. On such loads instantaneous reversibility of action is the ideal aimed at in the equalising plant, and cell-regulating switches would be worse than useless. Their action must be infinitely slower than that of the most sluggish booster, and we know that the results obtained by the use of some of those are anything but ideal. In reply to Mr. Foster's question as to the capacity of the Gary booster plant, the battery consists of 2 sets of 125 cells in parallel, the cells being each capable of giving 4,320 amperes for 1-hour, and 8,640 amperes for ordinary regulating purposes for shorter periods. Discharges up to 25,000 amperes have been taken from the two sets in parallel. The alternating-current regulation is effected by two split-pole converters each having a continuous rating of 6,300 amperes in either direction, which may be increased to 10,000 amperes momentarily as a true converter, or 14,000 amperes as an inverted converter. Mr. Rankin.

With regard to Dr. Garrard's remarks, an inductive diverter would be rather costly, and, as it would be used with the most expensive kind of booster—*i.e.*, one with a laminated field probably—it would place this type of booster at a still greater disadvantage, as far as price is concerned. In this connection I may say that if Mr. Foster suggested a system of tappings and switches on the booster field, which would be made to carry the total current, a diverter not being used, this method is impracticable. It is not possible to get a fine enough regulation, and the bringing of heavy tappings out of the machine would be a matter of considerable difficulty. I am pleased to hear Dr. Garrard say that I have explained the over-shooting properties of the Entz and Tirrill regulators in a way that appeals to the practical man. The possession of this property by those regulators is a strong argument in their favour, particularly when the inherent disadvantages of the diverter type of booster are considered. The Entz regulator has the further advantage of being extremely simple.

Proceedings of the Five Hundred and Twenty-ninth Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, 14th December, 1911—Mr. S. Z. de Ferranti, President, in the chair.

The minutes of the Ordinary General Meeting, held on 7th December, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

Messrs. C. W. Smith and C. F. B. Marshall were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Member.

Bertie Cecil Wilson.

As Associate Members.

Quentin Arbuckle.
Alfred Wilson Clegg.
John Murray Crawford.
Arthur Everitt V. Davies.
Michael Bruce U. Dewar, B.A.
Talbot Duckitt.
Arthur Edward French.
George William Hammond.
Arthur F. Harmer.
John Henry Hartley.
William Charles Kennett.
Percival André Lundberg.
Will Moore.
Henry Nimmo.
Ernest Edward Rogers.
Henry Rottenburg.
Charles Garrett Slack.
James Sinclair Terras.
Eric William A. Thomas.
William Watson.

As Associate.

Gerald Herbert E. Vivian.

As Students.

Philip Charles Batstone.
Sarat Kumar Chatterjee.
Alec. Broughton Doyle.
Oliver Howarth.
Atma Singh Sarkeria.
Charles Frederic K. Sharrock.
Cyril Lancelot Underwood.
Vernon Henry Wells.
Thomas Percy Wilson.

Donations to the *Library* were announced as having been received since the last meeting from C. Bright, F.R.S.E., A. Bursill, Professor H. S. Carhart, T. Harding Churton, The D. P. Battery Company, Ltd., W. Duddell, The Hill Publishing Company, Ltd., Lady Kelvin, Sir J. Larmor, Messrs. Merz and McLellan, H.M. Patent Office, F. H. Taylor, T. F. Wall, and S. Zehnder; and to the *Museum* from The Cambridge Electric Supply Company, Ltd., J. C. Chambers, and H.M. Post Office, to whom the thanks of the meeting were duly accorded.

The following paper, "Residence Tariffs," by A. H. Seabrook, Member (page 376), was read and discussed, and the meeting adjourned at 9.35 p.m.

RESIDENCE TARIFFS.

By A. H. SEABROOK, Member.

(*Paper first received 14th July, 1911, received in final form 23rd October, 1911, and read before* THE INSTITUTION *on 14th December, 1911.*)

PRELIMINARY.

The cost of supplying a residence consumer with electricity is composed of two parts :—

(*a*) "Standing cost," or the cost of being "ready to supply" him, made up of capital charges, the greater part of management costs, a small proportion of repairs, wages, coal, etc., and all charges which depend upon the maximum power he requires at any one time.

(*b*) "Running costs," made up of a small proportion of management expenses, and the greater portion of repairs, coal, wages, oil, stores, etc., and all costs which vary in proportion to the number of hours per annum he uses power.

No tariff is theoretically sound which does not differentiate between these two sets of variable costs, and which does not charge the consumer separately as to his standing costs and as to his running costs.

Another factor also has to be taken into account in tariff making, and that is "expediency." It may be quite justifiable on commercial grounds (and by "commercial grounds" is meant from the point of view of the balance-sheet of the undertaking) to take a line of action which, viewed by itself, appears to be unsound. A tariff which does not allow for expediency will be a failure.

Here are one or two examples of expediency :—

When the St. Marylebone undertaking was acquired from the Metropolitan Electric Supply Company the consumers were given the option of remaining on the company's flat rates of charge per unit, the Council's standard tariff being the Wright maximum demand system. The pedant said they must all be treated alike, new and old consumers. The Council said, "No, we shall lose business if we exercise compulsion." Thus, though in St. Marylebone a flat rate is not considered to be a correct method of charging, it is permitted in these cases on the ground of expediency.

Expediency has to be used in the case of severe competition ; for instance, lower prices are usually charged for energy for arc lamps outside shops than for inside lamps, this is on account of their advertising effect, and also because of the nature of gas competition. These arc lamps are used during peak-load time, and there is no ground for making a reduced charge except on that of expediency, but the effect upon the balance-sheet is beneficial.

Again, if a residence consumer in St. Marylebone adopts the "telephone" system of charge, which necessitates the complete wiring of the premises for lighting, and the exclusive use of electricity for artificial lighting, he can have units for all other purposes at 1d. each. Some of these "other uses" come on the peak and some do not, and in many cases there is no apparent justification for supplying them at 1d. per unit, but the procedure induces extended use of electricity for lighting, and it practically amounts to this, that the whole of the standing charges are put on the lighting business instead of being divided up between the lighting and the other uses, and "other uses" units are merely charged with the additional cost (capital and revenue account) of supplying them. Charged in this way 1d. per unit shows a profit. By itself, it may not appear to be sound, but from the balance-sheet point of view it is quite good.

It cannot be said that any hardship is thus imposed upon lighting consumers, because the 1d. units are available for any one who likes to use them. Moreover the business is remunerative at 1d. per unit, and if a higher price were charged—that is, if the full present standing charges were put on the "other uses" units, the "other uses" business would not be obtained.

The principle of basing the charge for additional output on the cost of additional output was insisted upon and firmly established at the Local Government inquiry at West Ham in 1909, and has been generally supported since by eminent authorities on electricity supply.

Characteristics of a Residence Tariff.

The characteristics to be desired in a residence tariff are :—

1. It should ensure a proper return from each consumer upon the total cost of supplying him, this cost being made up of standing and running charges, and the ideal tariff must take into account variables of each, and not assume them constant for all consumers.

2. It should be as simple as possible and capable of easy explanation to the consumer.

3. It should render unnecessary the use of more than one meter and one system of wiring, however varied the application of electricity, and it should hold out special inducements and facilities to consumers to make the freest use possible of the electric service for all the purposes that it can be adapted to ; it should facilitate the installation of the greatest number of points and encourage the long-hour use of electricity for lighting.

4. It should be cheap in application as regards accountancy, book-keeping, and labour generally, and should eliminate as far as possible complaints from consumers, which, of course, means a saving in labour.

5. It should possess great flexibility as regards the number of lamps installed, so that a consumer may install and pay for exactly the amount of light he requires, and he should not be charged on any arbitrary assessment based on the amount of light which is considered necessary for his purpose.

Residence Tariffs at Present in Use.

These may be put under three heads:—

(*a*) *The Flat Rate per Unit.*—This is the most common system of charge; it does not take into account the consumers' demand but merely his consumption of units.

(*b*) *Flat Rate Charge per Kilowatt of Maximum Demand and no Charge per Unit.*

(*c*) *Hopkinson Differential Rates.*—These consist of a primary and secondary rate of charge for standing and running costs, thus charging for maximum demand required as well as for units used. There are various methods of applying the principles laid down by the late Dr. John Hopkinson.

The following are some of the best known varieties:—

1. Wright maximum demand system.
2. Norwich or rateable value system.
3. Detroit system.
4. Contract demand system (Handcock and Dykes).*
5. Glasgow system.
6. "Metropolitan" system.
7. "Telephone" system.

These groups will now be considered in order to ascertain how far they meet the requirements as set out on page 377.

(*a*) The Flat Rate per Unit.

By this tariff the consumer is charged by meter so much per unit, with or without discounts, and regardless of his maximum demand. It therefore ignores an important item of cost, viz., standing charges, and it assumes that all consumers require the same proportion of units to their maximum demand, which is unsound and theoretically indefensible. For example, in a district where the flat rate is 4d. per unit, the occupants of two houses would be charged the same price per unit even if one were away for half the year and the other were generally at home throughout the year. It is obvious that one consumer is overcharged and the other is undercharged.

Another more serious objection, is that separate wiring has to be

* *Journal of the Institution of Electrical Engineers*, vol. 41, p 332, 1908, and vol. 44, p. 57, 1910.

installed before electricity can be employed for "other uses" than lighting, because consumers will not pay 4d. or 6d. per unit to run kettles, irons, toasters, and such apparatus.

There is a growing tendency on the part of residence consumers to make use of such auxiliary apparatus, and unsuitable tariffs should not be allowed to stifle the demand which is being so carefully and assiduously cultivated by manufacturers and some electric supply managers.

There is no doubt that auxiliary apparatus merely requires to be brought efficiently and tactfully to the notice of consumers and they will adopt it. In residence districts where suitable tariffs are in force the aggregate business in other uses is large and is rapidly increasing, though it may be made up of small items. This business may be encouraged to such an extent that these "other uses" units will yield as valuable and important a proportion of the total revenue as the power load in industrial areas. In fact, it would not be unduly optimistic to say that they will eventually become more important, as there is a bigger public to use electric heating and cooking than there is to use power, and the prices charged for electricity and electrical apparatus are now sufficiently attractive to encourage a great and immediate expansion of business.

The flat rate per unit has another serious drawback. It does not encourage the long-hour use of electricity for lighting, such as basement lighting, a most desirable class of load which cannot be obtained in any quantity even at as low a flat rate as 3d., but which a differential tariff will nearly always secure, because the low secondary rate encourages the free use of electric light in dark places and on dull days. Where a flat rate per unit is in force, gas is used in basements and during dull weather, leaving to electricity the evening peak lighting. It is not surprising that the organs of the gas industry view with profound dislike, veiled by ridicule, any advocacy of a simplified differential tariff for general domestic electricity supply.

In spite of the foregoing statements, there is little doubt that "expediency" demands a flat rate for lighting as an alternative to the differential tariff, but it must be a high flat rate. say not less than 6d. per unit. The reason is, that some consumers use electricity for a very few hours per annum, and it is possible that they might pay as much as 2s. per unit on the Hopkinson system. Though this may be justifiable from the point of view of cost, as it can quite easily be imagined that certain consumers may cost fully 2s. per unit to supply, he would be a bold supply manager who tried to get such a figure.

An alternative flat rate of 6d. seems a high enough one for most districts, practically none but short-hour consumers would adopt it, and they would probably not be remunerative. It is, however, a useful tariff to have for the purpose of fixing up consumers temporarily, and in cases of changes of tenancy, short lets, sub-lets, and new-comers, then the differential tariff can be put to them at the convenience of the supply authority's district representatives.

Some of the London electric supply companies were severely criticised recently for raising their flat rates from 5½d. to 6d., but it was the proper and correct course for them to adopt, as they were introducing a differential tariff, and were therefore compelled to keep the flat rate high. It requires strength of mind to do a thing which is bound to be temporarily unpopular with consumers, even though undoubtedly beneficial to both consumers and undertaking in the long run.

As regards the advantages of the flat rate, it is extremely simple, cheap as regards accountancy, meter-reading and collecting, easily understood by the consumer, and disputes are quickly adjusted.

(*b*) Flat Rate per Kilowatt of Maximum Demand.

This is analogous to the unlimited "telephone" service rate, and was a common system of charge in the early days of electricity supply, when only dusk till dawn supplies were given.

It consists of a weekly or monthly sum per lamp or per kilowatt or part of a kilowatt installed, and has generally been applied to lighting supplies only. No meters are used, as there is no energy charge.

From the consumer's point of view it is the simplest of all tariffs, but it will only be adopted by long-hour users. Probably the best known application in this country is that by the Fixed Price Light Company, who have successfully introduced it into small residences in South London.

It has been applied on a small scale in St. Marylebone for artisans' dwellings, consisting of one-, two-, and three-room tenements. The price per tenement is calculated, in the case of kitchens and sitting-rooms, in such a way that if the consumer uses his lamps day and night, the price per unit obtained would be a little under 1d., and lower in the case of bedrooms. In practice there is not much difficulty experienced from consumers wasting light, as in these blocks of tenements the caretaker is a person of considerable importance, and exercises a good deal of control over the tenants.

The price per lamp per week includes lamp renewals, and also a sum calculated to write off within a reasonable period the capital expended in wiring. The schedule of charges is as follows:—

Single-room Tenement.

7d. per week (one 25-c.p. osram) made up of:—

Current	4d.
Lamp renewals	2d.
Installation repayment	1d.

Two-room Tenement.

Kitchen ...	7d. per week (25-c.p. osram).
Bedroom ...	5d. per week (25-c.p. osram).

The latter made up by—

Current	2d.
Lamps	2d.
Installation	1d.

Alternative for bedroom 3d. per week (one 8-c.p. carbon) made up by :—

Current	2d.
Installation and lamp	1d.

Three-room Tenements.

Kitchen ...	7d. per week (one 25-c.p. osram).
Sitting-room ...	7d. per week (one 25-c.p. osram).
Bedroom ...	Same as for two-room tenement.

There is a proviso that if a bedroom is used as a bed-sitting or a sitting-room, the 7d. rate applies.

Tenants are not obliged to use electric light in all rooms.

The cost of slot meters renders a metered system in these dwellings prohibitive.

There are 52 tenements in the block consisting of :—

22 single-room.
20 two-room.
10 three-room.

Stair Lighting.—The landlords pay an annual sum of £7 10s. for eight 25-c.p. osrams burning for 2,000 hours per annum, and it includes wiring depreciation but not lamp renewals.

Lavatories.—There are 12 of these, and each is fitted with a bolt switch, so that the lamp only lights when the door is bolted from inside. The circuit is controlled from the caretaker's quarters.

The annual sum paid by the landlords for current and installation, but not lamp renewals, is £4 4s. for twelve 5-c.p. carbon lamps.

The result of the first year's working will be found in Appendix IV. in the form of a report from the author to the St. Marylebone Electric Supply Committee.

About half the tenements adopted the system immediately it was available, and as new tenants come in all the tenements will be fitted up.

If in the future the tariff is generally applied in the district, it appears from enquiries made that by arrangement with the landlords the charge for electric light can be included in the rent, and the flats can be let inclusive of light.

As it is, there is a tendency for flat owners to insist upon the exclusive use of electric light in their flats on account of the saving

in decorations, etc., and there is little difficulty in inducing landlords to make this compulsory where contracts for a period of years have been entered into for electric lighting arrangements.

Messrs. Handcock and Dykes have put into operation a similar system, but a limiter is used in conjunction with it, the charge being based on the watts of maximum demand at which the limiter is set to flicker. The consumer states the number of lamps he wants to use simultaneously and the limiter is set accordingly. It is as expensive, however, to put in a limiter as a meter.

The flat rate per kilowatt of maximum demand system has very wide possibilities among small residence consumers where meters are impracticable on account of cost, and it seems to be the only solution at present of the small consumer problem; at the same time it is a very satisfactory solution, both to suppliers and consumers.

It is not proposed in this paper to set out in detail any tariffs which have been the subject of papers read before the Institution, nor those which have been detailed in the British technical press, as most members will be already familiar with them.

One typical American flat rate per kilowatt of maximum demand might be mentioned, that of the Vineyard Sound district of Massachusetts. It is stated that all new residence business is being gained on this system, and the use of meters is diminishing. The rates are based on the tungsten lamp, payments being dependent upon the maximum number of lamps in use at any time.

The *Electrical World* * states: "Usually the customer's word is taken as the basis of a contract" (which seems a loose method to adopt) "and in case of any question a Wright demand meter readily settles any difference."

A charge of 9½d. per week is made for the first 25-watt lamp connected in a residence, the second and third are charged at 6¼d. each per week, and all in excess of these are charged at 4¼d. per week each. "Convenience" lamps (*i.e.*, cupboards, larders, bath-rooms, etc.) are permitted in the ratio of 1 to 3.

The customer is not expected to use over one-third of his connected lamps at any one time, without special permission from the company. It is evident that this particular company serves a district containing chiefly small houses.

One would imagine that the inspection costs would be heavy with such a system, as no mention is made of locked lamps to prevent changing the wattage. The charges appear high, but electricity costs are high in the States, and the flat rate per unit in the Vineyard Sound district is from 12½d. to 7½d. per unit net.

A good example of an American controlled flat rate per kilowatt of maximum demand is that in force at Superior, Wisconsin.

The minimum amount which can be contracted for is 100 watts. The rate is 4d. per 32-watt lamp per week. In order to cater for the flat-iron business, which is such an important source of revenue in the

* *Electrical World*, vol. 57, p. 826, 1911.

States, a separate flat-iron circuit is connected on the service side of the limiter, and 2s. 1d. per month is charged per iron.

This appears to be the only case on record where apparatus other than lighting is charged for on a flat rate per kilowatt of maximum demand, and considering that it is possible to toast, boil, grill, heat a room, cook, and do sundry other things with an electric iron, it seems a delightful system from the consumer's point of view. The limiter flickers the lights when the lighting watts contracted for are exceeded. Those adopting this system are nearly all small consumers.

The *Electrical World* * in an article says that while it may seem strange that these consumers will sign a new form of contract (most of them are changing over from the flat rate per unit) agreeing to pay the company as high an annual amount as they were on a meter basis, this fact is easily accounted for by the eagerness of the average person to be free from the fear of running up large bills when on a meter basis, and by his desire to know exactly in advance what the electric light service will cost.

The conclusions one may come to with regard to the flat rate per kilowatt of maximum demand are :—

1. It is only suitable for small long-hour users.
2. A "limiter" spoils it on account of increased capital cost, which the system is mainly designed to avoid.
3. The system is preferable for small consumers to one using slot meters, because the latter has the objection of the flat rate per unit resulting in a low load factor and restricting the use of electricity for all purposes, and besides, the cost of meters is too great for small installations.

(*c*) Hopkinson Differential Rates.

It would be difficult to find an electric supply manager who would deny that the Hopkinson principle is the only scientifically correct basis of charge, whether he adopts it or not himself.

The question then arises, Why are there so many flat rates per unit in force ?

The answer is, Because of the difficulty of applying the Hopkinson principle in a simple and easily explained and understood system of charge, which complies with the requirements of expediency as well as with the laws governing supply costs.

The following extracts from the *Electrical World* † serve to indicate the views held in the States on the subject of tariff making. In an article on the Detroit system it is stated that "It is now generally accepted that an equitable system of charging is one based on the consumer's maximum demand, and that the average rate per kilowatt-hour which he pays must be dependent upon the number of hours that the maximum demand is used for the year."

* *Electrical World*, vol. 56, p. 597, 1910. † Ibid., vol. 54, p. 39, 1909.

Again, referring to an electric convention, it is stated* that "one gratifying feature of the discussion was the unanimity of opinion expressed on the subject of rates. The authors of papers and discussions practically all agreed that a proper system of rates for electric service should recognise the two elements—namely, fixed charges and variable running expenses, and that, whatever the exact figures adopted by a company, these two elements should enter in making the kilowatt-hour rate." Further on it states: "It is indeed difficult for those who have studied this matter for years to realise the ignorance of the first fundamental principles of rate-making among some of the smaller companies."

In this country the last sentence will apply to the large as well as the small supply authorities, because most of the large ones which should lead the way are peacefully sleeping upon inconsistent flat rates per unit.

In spite of this, one hears frequently the expression of opinion that tariff discussions are uninteresting and unnecessary. This opinion is nearly related to that sometimes expressed by supply managers, who appear to be satisfied because they have practically all the houses in their area connected to the mains. One wonders how many of these houses are using more than 10 per cent. of the possible amount of electricity they could be induced to use were a suitable tariff combined with a business-getting department in existence.

It is fallacious and misleading to claim that there is any district in this country which is so soaked with electricity that it could not be made to take up many times the number of units it uses now, greatly to the financial advantage of the company or corporation supplying them.

Turning again to the *Electrical World*, it states in a leader dated August 25, 1910†: "Those building rate systems should first of all recognise the three factors—kilowatt-hour, maximum demand, and consumers' costs—which enter into the expense of serving any consumer, and once these are fully recognised and reckoned with the exact form or name of the rate system is not of so much consequence."

On November 3, 1910, the *Electrical World* gave an account of the Illinois Electric Convention,‡ and stated that the Committee on Rates finally took up the differential rate, which, in general, is the form advocated. It was the unanimous conclusion of all who have studied the subject of rate-making that rates, if equitable, must bear a definite relation to load factor.

Thus it would appear that the correctness of Hopkinson's principles are quite as fully agreed in the States as here. In both countries the reason why tariffs on these principles make such little headway is the same, viz., the difficulty in applying those principles in the form of a simple tariff.

* *Electrical World*, vol. 54, p. 1075, 1909. † Ibid., vol. 56, p. 412, 1910.
‡ Ibid., vol. 56, p. 1036, 1910.

The best known of the Hopkinson systems are :—

1. The Wright System.

This system is well known, and needs no description. Its main disadvantages are :—

(*a*) It is impossible for the consumer to understand it, and that is a most serious bar to obtaining new business.

(A suitable tariff is one which is a "business getter" in itself.)

(*b*) It is practically impossible for the consumer to use electricity for other purposes than lighting, unless the number of units per quarter at the primary rate is agreed and the demand indicator reading ignored, in which case the system really comes under one of the tariffs described later on.

(*c*) It is expensive in capital cost, meter and accounts department, and the cost of settling consumers' complaints is excessive.

(*d*) Consumers do not, as a body, appreciate the value of the low secondary charge, consequently the system tends (with a few exceptions) to restrict the use of electricity.

2. Norwich, or Rateable Value System.

This is a differential system, in which the primary rate is a fixed percentage of the rateable value of the house, all units being charged at a low price of 1d. or thereabouts.

It has several advantages, being extremely easy for the consumer to understand, and therefore a good "business getter"; it is cheap in application, it encourages the use of electricity for other purposes than lighting, only one meter and system of wiring is required, and it encourages liberal use of electricity for lighting.

It has, however, several serious drawbacks. It is an "inflexible" rate, because it assumes that each consumer in each similarly rated house requires the same number of watts for lighting, whereas in practice it is found that the requirements of different persons in similar houses differ enormously. One must assume that a middle course is taken in the assessment of primary charge, the result being that the person who requires double the normal amount of light will adopt the system and thus save considerably in his accounts, and the person who, on account of meanness, impecuniosity, or preference, uses less than the normal amount of light, will not adopt it because it will not pay him.

With a Hopkinson tariff the primary charge should be based on the consumer's lighting installation, whether the latter be liberal or otherwise.

The second serious defect in this system is that it relies upon houses assessed at the same amount for rating purposes requiring similar installations of electric light. This must be a serious difficulty in nearly all districts.

It makes it impossible to adopt the system in a district such as

St. Marylebone, as there is a great difference in the rateable value of a house with no grounds, garden, or outhouses, and a house of similar size with a garden and extensive outhouses.

Again, the rateable value of two houses of the same size and only one street apart from each other, may be very different. Position, at any rate in London, affects rateable value considerably.

The tendency for people to leave houses and occupy flats is increasing, and at one time it was thought the Norwich system of charging could be applied to flats—it turned out, however, to be a more unworkable case than the other, as apart from the rental value of blocks of flats varying in different districts, according to the facilities given by the landlords to the tenants and the age of the buildings, there is a considerable difference in the value of suites of the same size in the same buildings, due to the positions of the suites.

If factors are admitted correcting for locality, etc., the Norwich system might become possible, but that procedure opens up incalculable difficulties and vitiates the whole idea of the system.

3. Detroit System.

In this system the primary charge is based on the number of rooms in a house, etc., in the form of a predetermined number of units per room at a high price per unit, all additional units being supplied at a low secondary rate.

The author is not aware of any application of it in this country, but it is in use in Detroit and other cities in the States. The South Suburban Light and Power Company apply it as follows :—

For the first 3 rooms	...	100 watts per room.
" next 4 "	...	60 " "
" " 5 "	...	40 " "
" " 6 "	...	35 " "
" " 7 "	...	25 " "
All over 25 "	...	25 " "

All rooms are counted, and halls, pantries, bath-rooms, lavatories, are called rooms for the purpose of assessment.

The watts assessment having been fixed, the monthly charge (up to 10-k.w. capacity) is at the rate of £10 per kilowatt per annum, and the secondary charge (up to 12,000 units per annum) is 2½d. per unit.

In arguing the advantage of this system, Mr. A. C. Einstein (*Electrical World*, November 3, 1910*) points out, in comparing it favourably with the demand indicator system and connected load basis of primary charge assessment, that for the general run of consumers the cost of demand indicators in addition to meters is a burden which supply companies endeavour to avoid, and many companies now base the primary charge on a percentage of the watts connected.

* *Electrical World*, vol. 56, p. 1077, 1910.

He then points out the objections of the primary charge being based on the connected load, one of which is that the economically minded consumer who puts in a few lights is in a more favourable position than the man who freely illuminates his house.

Another objection is that this (connected load) basis of arriving at the primary charge restricts the business of the supply company, because it discourages the consumer from installing convenience and decorative lamps. Another of Mr. Einstein's objections is that the consumer may increase his connected load immediately after inspection by the company. He then goes on to advocate the "room" basis of assessing the primary charge.

All this is interesting because it describes the line of thought which led Mr. Einstein to adopt the "room" basis of primary charge, and as this system has some of the disadvantages of the Norwich system, and because the author is so firmly of opinion that the "connected load" is the correct basis for the primary charge, he will endeavour to show that the disadvantages of the connected load basis, pointed out by Mr. Einstein, are easily surmountable, and that more mature consideration would have saved him from adopting a system which, unless he made it compulsory, would only attract the extravagant consumer, and then having obtained him would not charge him with his proper amount of primary cost, because the primary charge on the room basis encourages him to increase his maximum demand at no increased charge. Unless the primary charge is fixed so low that a still greater loss is incurred in supplying the extravagant consumer, the more economical consumer will not adopt it, and there are many consumers who would not increase their illumination simply because they were told that if they did there would be no extra charge.

Turning to Mr. Einstein's first objection to the connected load basis, viz., the advantage of the mean consumer over the liberal consumer, it is the practice in charging on the connected load basis to count for assessment purposes only "active" lamps; "inactive," "convenience," or "decorative" lamps are ignored. This is quite an established practice and answers excellently, because it does not deter the consumer from installing these extra lights which on account of their diversity, far from being objectionable, actually improve the consumer's load factor. There is no necessity on the connected load basis to cause any restriction of the installation.

Mr. Einstein's next objection is that the consumer may vary his connected load once it has been assessed; this, of course, implies the dishonesty of the consumer, because if he does this he is deliberately taking some one else's property without paying for it.

General experience is that although there are some consumers who will do this kind of thing, they are a very small number, and under a properly drawn contract they can be prosecuted if it is desired to go so far; where it has been found to have been done it has generally been unwittingly and not deliberately. Where it is suspected, a demand indicator will generally show it up.

Even granted that this were done to a considerable extent, it still leaves the connected load basis preferable to an unlimited room basis, as it is applicable to all consumers and not a section, and each man pays for exactly the size of installation he wants, whether it is large or small.

An important point in any connected load basis is that it should be stipulated that no other artificial illuminant but electric light should be used; it is perfectly easy to get consumers to agree to this.

The room basis as applied in Detroit is slightly different to the method of application used by the South Suburban Company. It is more complicated and less easily understood by the consumer, because in place of a plain charge per room the primary charge is in the form of so many units per month per room.

The schedule is as follows:—

The charge is 8d. per unit up to a point where the customer's consumption equals 2 units per month for each of the rooms in the house which are counted, and 2d. per unit for all electricity used in excess of that amount.

Only the principal rooms are counted; those not counted are kitchen, lavatory, store-room, and 3 bedrooms, also unfurnished attics, closets, bath-rooms, stairways, halls, servants' rooms, pantries, porches, and vestibules.

Fans, flat-irons, stoves, and cooking devices and other uses than lighting are *not* counted in the demand charge, so that the consumer can use these devices at the secondary rate of charge.

Some of the Detroit real estate dealers are inserting a clause in their leases providing for the exclusive use of electric light in their rented residences.

The advocates of the system point out, as Mr. Einstein does, that it encourages the free installation of "convenience" lamps, whereas the connected load basis actually discourages them, which, as has been shown, is quite a wrong assumption.

The Detroit system, as employed at Toronto, Canada, is in the form of a primary charge of 5d. per room per month, and 1¼d. per unit energy charge, and the following rooms are not counted: unfurnished attics, passage-ways, bath-rooms, cellars, porches, and out-buildings.

At Milwaukee the system is applied as follows, and is rather more complicated than at Detroit. An annual contract is insisted upon.

(*a*) A primary charge of 6d. per unit for (1) the first 4 units per month for each of the first four active rooms; (2) the first 2½ units per month for each of the active rooms in addition to the first four.

All rooms are counted as active except three bedrooms, bath-rooms, basement, garret, closets, and back porch.

(*b*) The secondary charge is 2½d. per unit for all energy in excess of that paid for at the primary rate in (*a*) up to a total of 100 units, and 2d. per unit for the next 900 units.

4. Contract Demand System.*

On this system the primary charge is based on the connected load, and the consumer states his maximum demand required in kilowatts, at which figure a limiter flickers the lights when that maximum demand is exceeded.

The system has many advantages as regards simplicity, and would be almost ideal if lighting were the only use to which electricity can be put.

The disadvantage which puts the contract demand system right out of court is the impossibility of using electricity for other purposes than lighting ; irons, kettles, etc., are all barred because they cannot be used at the high-lighting rate of charge.

The originators of the system do not seem to mind if "other uses" are barred unless the full lighting fixed rate is paid, because they say the "other uses" apparatus is on at peak load time, and therefore ought to bear the full standing charges. True, a portion of it does come in at peak, but a large portion does not, and in practice it is found that the diversity of this class of load taken in bulk entitles it to be charged at a much lower rate than lighting, which has practically no diversity.

Authorities on tariff making, both in this country and abroad, are agreed that energy for "other uses" than lighting can profitably be charged at the secondary charge only, and that no primary charge should be attached to it. The rate per unit for the secondary charge must, of course, be fixed by each undertaking according to its cost of supplying additional output.

For instance, this secondary rate of 1d. per unit for other uses in the case of St. Marylebone would be somewhat speculative if consumers were not bound to use no other artificial illuminant but electricity before they could obtain the 1d. rate for other purposes.

5. Glasgow System.

The system recently put into force in Glasgow is as follows :—

Up to 800 hours' use of the maximum demand the primary charge is 3d. per unit (the present flat rate of charge) and all additional units 1d. —the secondary rate.

Mr. Lackie found that the average residence consumer used his maximum demand for lighting for 800 hours per annum, and in his report on the subject, he says : "I propose that the initial charge for the first 800 hours use of the maximum demand should be on the principle of a proportionate number of 3d. units in each two-monthly account period, all the units consumed over this fixed quantity in the period being charged at 1d. This would let the consumer see in every account that as a result of using energy for other than lighting purposes, so many units are charged at 1d."

* Handcock and Dykes, *Journal of the Institution of Electrical Engineers*, vol. 41, p. 332, 1908, and vol. 44, p. 57, 1910.

The trouble is, however, that the consumer would be sadly alarmed at his first bill if he put in a kettle and an iron.

Suppose he had 1 k.w. of maximum demand for lighting and used 800 units per annum = £10, then he put in the kettle, iron, and perhaps a hot plate, taking altogether 2½ k.w. He will argue, in his innocence, that he will use many units over the 800, say, a further 800 at 1d., and his bill will then be £13 6s. 8d.; but what really happens is that he had to use 800 times—about 2 k.w. instead of 1 k.w. (owing to his "other apparatus") at 3d. per unit, which is £20, and then there will be his extra units (if he gets any, which is unlikely) at 1d., so that this system will work out very differently from that expected by the consumer, and instead of his units of increased use being at 1d. per unit they will be 3d.

The only way to get over this difficulty is to assess the lighting maximum demand. If Mr. Lackie did this (he may be doing it now), and then turned his 3d. units into a quarterly or annual sum and charged all units at 1d. he would be very near to a satisfactory tariff and to that which is advocated at the end of this paper.

6. "Metropolitan" System.

The "Metropolitan" system, which is used by the Metropolitan and the Brompton (London) Electric Supply Companies, is based on the connected load and consists of three charges:—

(*a*) Primary kilowatt charge.
(*b*) First energy charge 2d. per unit, the amount in £ s. d. at 2d. per unit to be equal to the amount of the annual primary charge, then all units in addition are charged at:—
(*c*) The second energy charge at 1d. per unit.

The Metropolitan Company's official notification is as follows:—

New Contract Tariff.—"The company are prepared to quote consumers in Paddington a fixed annual charge payable by quarterly instalments in consideration of which all units supplied, whether for lighting, heating, or cooking, will be charged at 2d. up to the value of such annual charge, and for all in addition at 1d.

"The amount of the annual charge will, of course, depend upon the size and nature of the installation, and a quotation will be submitted upon application."

The chief advantages of this system are that separate circuits and meters for different classes of lighting and for heating, etc., are rendered unnecessary, and that owing to the price per unit being so very low, the use of the company's supply can be greatly extended for all purposes without undue expense.

The only difference between the "telephone" system (as the contract system is called in St. Marylebone) and the "Metropolitan" system, is the intermediate energy rate of 2d., and one would imagine that very few consumers get the 1d. rate. The author has argued the

point with Mr. Highfield at various times, and that gentleman's claim is that the 2d. units will apply to current used for kettles, irons, etc., at which price consumers can afford to use them, and that where more "other uses" apparatus is put in, such as radiators and cookers, the consumer gets on the 1d. rate. It would be interesting to hear whether consumers do get any 1d. units in actual practice.

There are so many good points in the system not possessed by systems of charging other than the "telephone" system that this intermediate charge of 2d., even if it does complicate the straight annual charge and 1d. per unit system, cannot be considered to be any serious disadvantage provided it is found that consumers actually do get on to the 1d. rate.

The only objections to it in addition to this complication and proviso are :—

(1) That the ordinary consumer cannot afford to pay 2d. per unit even for kettles and irons if extensive use is made of them, and (2) that it is impossible for the consumer to know when he is off the 2d. and on to the 1d. rate, which is one of the most serious objections to the Wright system. As long as he thinks he is on the 2d. rate he will try and be careful and economise, but if he knows that all units are at 1d. as on the "telephone" system, he will be more inclined to make free use of the service.

The "Metropolitan" system depends, of course, upon the assessment of the lighting maximum demand, and perhaps the discussion will elicit some particulars as to the method of assessment.

One of the technical journals in commenting upon the system remarked that if it were desired to modify the "telephone" system it would be much better to omit the fixed annual charge and merely to charge a predetermined number of units at a higher price, such as 6d. per unit, all units in excess being charged at 1d.

This annual or quarterly charge is the whole essence of the "Metropolitan" and "telephone" systems, and it was introduced entirely to get rid of the difficulty in explaining to consumers the Wright maximum demand system, and the journal referred to above completely misses the main object of modern tariffs, which is simplicity and the abolition of the primary charge in a differential system of so many units at a high rate of charge and so many at a low rate, because no one has yet been able to convince a dissatisfied consumer that the units at the high rate of charge are not jumped at by the office boy, and that there are accurate instruments used for determining these units.

7. The "Telephone" System.

This is a differential tariff based on the connected lighting load.

Appropriately enough the idea was first suggested to the author by Mr. Arthur Wright when discussing rates of charge for small consumers. Mr. Wright said that the revenue from the small consumers would hardly stand the cost of a meter, and certainly not a demand

indicator as well, and the conversation then turned round about the desirability of fixing the maximum demand and the number of units at 8d. per annum, and then on to quarterly and annual charges based on an assessed maximum demand.

The system as described in the paper was the outcome of that conversation and of the various improvements made by the staff at St. Marylebone as experience was gained. The author fears that a good deal more credit has been awarded to him than he really is entitled to, as the only thing about it which he fixed was the name "telephone," and that was adopted for the following reasons:—

1. Practically all consumers, if not actually telephone subscribers, are acquainted with the system of charge for the telephone, which is roughly an annual sum, payable in advance, and 1d. per call.

2. Calling the system the "telephone" system immediately causes people to think of the telephone charges and accustoms them to think of payments in advance. People in St. Marylebone could not have been induced to part with £25,000 in prepaid annual sums if there were not an excellent precedent to argue with in the telephone charges. The annual sum for electric lighting in a large number of residences and flats amounts to approximately the same figure as the Telephone Company's, which is a useful coincidence.

3. Calling it the "telephone" system decided many people to adopt it who argued, "Suppose I am away and sub-let my house or have to leave for some reason, and the house remains empty or I give up the house altogether, shall I get a rebate from the annual charge?" These are admittedly difficult cases, but they are answered that "no rebate is allowed by the Telephone Company under similar circumstances, but if you sub-let your house you can also sub-let your annual charge, whether for the telephone or electric light, and your tenant can pay you this proportion, but if you leave your house you get no rebate from the Telephone Company nor from us."

4. It has frequently been most useful to be able to show a consumer what the Telephone Company's annual charge covers in standing and capital charges and then to explain how in like manner electric supply standing charges are almost identical, and that it costs the Telephone Company and the Electric Supply Undertaking a certain definite sum to be "ready to supply" him apart altogether from the number of calls he makes or units he uses, and then to show him from which costs the 1d. per call and 1d. per unit are made up. It would be most difficult to explain all this to the consumer if the Telephone Company did not exist to make use of. Thus the name is purely a "selling point."

Briefly the "telephone" system is:—

(*a*) A differential system with its primary charge based on 70 per cent of the connected lighting load at £14 per kilowatt per annum, not counting convenience and decorative lights and not counting any watts installed for other uses than lighting.

The secondary charge is an energy rate of 1d. per unit.

(*b*) The exclusive use of electricity for artificial lighting is insisted upon.

(*c*) The primary charge is payable annually in advance or quarterly at an increase of 10 per cent. in the price.

(*d*) The primary charge is not increased in subsequent years provided the consumer does not increase the wattage of his lighting installation.

(*e*) Maximum demand indicators are used in all but small installations and are put in circuit with the whole installation—lighting and "other uses"—not for charging purposes, but as a guide in noting the load factor of the entire residence installation. When sufficient information has been obtained these will be discontinued.

(*f*) It will be seen that the standing charges of the entire residence service are based on the lighting installation.

The advantages of the system are :—

1. Each consumer pays his share of standing and running charges and separately.

If he only chooses to use his service for lighting, that is his loss, the fact remains that it is open to him to use it for other purposes than lighting at no increase in the annual charge.

2. The system encourages longer hours' use per annum of lighting and does not encourage economy in units.

3. A large amount of "other apparatus" than lighting can be connected to the lighting circuits without the expense of separate circuits and meters.

4. The system has not the disadvantage which many differential systems based on the connected load have, namely, discouraging the free installation of lighting points, because convenience and decorative lamps are not counted.

5. The system has not the objection which many differential tariffs have, viz., assuming that all consumers of equal size require the same amount of light. On the "telephone" system the consumer has to wire his house throughout, but he can have and pay for the number of lighting watts that he wants.

6. The system is extremely simple in application, merely consisting of a quotation of so much per annum and 1d. per unit, and it is easily understood by the consumer.

7. It practically eliminates the possibility of complaints, as these can only refer to the number of 1d. units, and consequently strict meter accuracy is not so essential as when units are being charged at 4d. and 6d.

"Telephone" System—Assessment of Primary Charge.

Seventy per cent. of the lighting watts installed may be considered high (several electric supply managers have adopted 60 per cent.), but convenience and occasional lights, such as those used in cellars, pantries, bath-rooms, lavatories, larders, and occasional rooms are not counted,

nor are lamps counted which are used for purely decorative purposes, provided there is already 1 watt per square foot of floor space (based on tungsten lamps) installed in the room. This proviso is obviously necessary to prevent a consumer claiming nearly all the lamps installed in a room as decorative, which in some large houses it would be possible to do.

It is found in St. Marylebone that a very small house or flat uses on the maximum demand system 80 per cent. of the lamps installed at any one time; as the size of the house increases the percentage decreases to 33⅓ in the largest houses. The larger the house, however, the greater the number of convenience and decorative lamps, which brings out the 70 per cent. about right.

Some percentages of connected lighting load on which primary charges are based in the United States may be useful.

Mr. H. C. Abell, in the *Electrical World*, gives some interesting figures.* He says from his experience residences were found to have a demand of relatively 25 per cent. of the connected load at the time of maximum station demand, but by analysis it was found, owing to the increased investment necessary in distribution, etc., that this should be increased in calculating the primary charge per kilowatt.

Tentative figures of 60 per cent. of the connected load for the first 10 lamps, and 33⅓ per cent. for all other residential lamps, were considered to represent the active and residential demand, the average of all working out to about 50 per cent. of the connected load for the residential demand instead of 25 per cent. In Madison, Wisconsin, the assessment was fixed by the Wisconsin Commission † as 60 per cent. for the first 10 lamps (or 500 watts) and 33⅓ per cent. for all in addition, and in Ripon it was fixed at 40 per cent. all round.

In Chicago it was found that the average residence percentage of maximum demand to watts installed was as follows:—

300	watts installed	90	per cent.	maximum demand.
500	" "	64	"	"
1,000	" "	48	"	"
2,000	" "	46	"	"

It does not appear to be usual in the States to ignore convenience lights in a differential system where the primary charge is based on the connected load, because it is frequently stated by American supply men as an objection to the system, even where such a low figure as 40 per cent. of the lighting installation is taken as the basis of assessment, that it discourages the installation of convenience lights.

The author is of opinion that it is preferable to take a higher percentage and cut out convenience lights, because however low the percentage may be, if convenience lights are counted in the consumer will certainly be deterred from installing them, but a higher percentage

* *Electrical World*, vol. 56, p. 1479, 1910.
† Ibid., vol. 56, p. 568, 1910.

assessment and these lights counted out gives the same result and the consumer puts the extra lamps in. This, again, is a "selling" point.

"Telephone" System—Secondary Charge.

One penny per unit was taken for the secondary rate because it is a rate at which consumers can afford to use electric heating and cooking, as at that rate electricity can compete with gas.

One penny per unit is also quite a safe figure from the point of view of cost per unit in St. Marylebone, but this is a matter which each supply manager must consider for himself, because conditions differ in nearly every district. In some cases the rate could profitably be ½d., but it is a pity to charge as low a price as ½d. per unit for cooking and heating, unless for the six summer months only (¾d. per unit is now being seriously considered in St. Marylebone as a summer cooking-rate and 1d. in the winter), as there is such a large amount of business to be done at 1d. before there is any necessity to go any lower in price. As the apparatus is improved in efficiency and design those who have already dropped to ½d. will be rather sorry they did so. An efficient business-getting department would probably have prevented the necessity for dropping the price at this early period in the history of electric heating and cooking.

It would be possible to spend a very large sum per annum on a first-class expert heating and cooking department for business getting, and then save a lot of money as against a wholesale drop in price.

Another point in favour of the 1d. rate is that it is the same as the telephone charge of 1d. per call, which is of great assistance in introducing the tariff.

Exclusive Use of Electricity as an Artificial Illuminant.

This is one of the essential points of the system. It would be inadvisable at the moment to offer, with no restriction, 1d. per unit for all "other uses" than lighting in St. Marylebone, but if the exclusive use of electricity for lighting can be obtained and thus the full standing charge on the premises, then 1d. per unit for "other uses" is remunerative.

It is difficult to see the object from a business point of view of reductions in price which do not result in immediate gain in some other direction. The "telephone" system means a considerable reduction in price to consumers already using electric cooking and heating, at the maximum demand rate in St. Marylebone of 2d. and 1d., and it is preferable to use a reduction in price in such a way that one can say to a consumer: "I will do so and so for you if you will do so and so for me. You can have a reduced price for heating and cooking but you must give up all gas for lighting and give me your lighting business." It would surprise many people to know what the results are. A typical case may be cited, one of many. A consumer came to the

showroom and purchased a radiator. The showroom attendant immediately enlarged on the advantages of the "telephone" system, the result was that 19 gas-light points were changed to electricity, "telephone" system and maintenance contracts were obtained, and an order for several more radiators.

As time goes on, following the principle already set out of giving a reduction to consumers who will only use electric light, it might be possible to go as far as to say "that if you give us all your lighting, heating, and cooking, and you do not use gas at all, we will supply you with all the units at ¾d. all the year round instead of 1d."

Annual Charge in Advance.

In St. Marylebone, during the first two years of the "telephone" system, nearly £25,000 was received in annual payments in advance. Here again the Telephone Company's charge helped considerably.

An increasing sum is carried forward each year in the form of unexpired annual payments; this materially assists to increase the working capital of the undertaking. In a short time, in spite of the very large half-yearly payments on account of capital charges, there will be a credit bank balance on Revenue Account all through the year.

A large business is done in hire and hire-purchase, the capital expended on which it is considered preferable to write off at the end of each year instead of raising loans, and a large working capital is particularly useful in this case, which is only one example.

Altogether there is no reason why annual payments for electric supply should not be obtained in advance just as telephone subscriptions are.

Although quarterly payments in advance are accepted at 10 per cent. increase, the number of consumers paying quarterly is negligible.

Annual Charge in Subsequent Years.

Many consumers raised the point that once they were on the "telephone" system and had mixed up a lot of other apparatus with their lighting, they were in the hands of the supply undertaking and the future annual charge could be increased and forced upon them, because it would be most difficult and expensive for them to go back to their old rates.

To get over this the following is printed in large red type on all agreement forms :—

"The annual charge in future years will not be increased provided you do not increase the number, candle-power, and watts, of the installation as per schedule attached."

General.

It is difficult to imagine that any tariff monger would have the hardihood to claim that his pet form of tariff was perfection, and no

such claim is made for the "telephone" system, but the author believes that for the time being it is preferable to base the primary charge of differential residence tariffs on the connected lighting load.

It must be borne in mind, however, that when the complete electric service—lighting, heating, and cooking—is installed in residences, the proportion of lighting revenue to the total revenue per residence will be about one-third to one-half, and the whole aspect of residence supply will be changed, the lighting load factor will not then be the dominating factor; lighting and heating will be still essentially winter requirements, cooking, taken in the aggregate, will be largely non-peak. Many other accessory uses, such as fans, bath-water heating, polishing, ironing, etc., will also be found to be largely non-peak.

One point as to the diversity of the cooking load might be worth mentioning. From recording ammeter charts it is found in St. Marylebone that even where late dinners are the custom in an ordinary family, the midday cooking load is generally greater than the evening, and is perhaps due to the fact that the children, maids, governesses, etc., have a middle-day dinner, and also that a good deal of food is cooked in the middle of the day and early afternoon for the evening meal, as naturally the average cook prefers to leave as little as possible to be done in the evening.

A large number of these recording ammeters are kept going in order to ascertain the diversity of load in various residences and blocks of flats, and the information accumulating is most valuable.

In the Appendices also are copies of "telephone" system agreement forms, schedule forms, and renewal forms, copy of letters sent out to each "telephone" consumer, and to each consumer renewing the contract.

The author is keenly looking forward to the criticism of this paper because he believes that the "telephone" system is one specially adaptable to suggestions, at least in his own undertaking he has found it to be so, and he is anticipating that the discussion on the paper will help still further to eliminate defects and effect improvements.

Probably the optimist will say that in a few years' time, when electricity is universal, it will be possible to offer a flat rate per unit of 1d. or less, and it will not be necessary to bother about differential tariffs. It is difficult to see how that can come about, because if all residences used electricity for all the purposes for which they use at present electricity, coal, gas, and oil, there will always be the long- and short-hour users, and they cannot be fairly charged at the same rate per unit. It seems inevitable that even if it were found profitable to charge an average price of 1d. per unit for all residences supplies, that 1d. would be made up of consumers who cost ½d. and others who cost 2d. A universal flat rate must be as unfair in the future as at present unless some genius abolishes load and diversity factors.

APPENDIX I.

Form "G" is a "telephone" system agreement form as used in St. Marylebone.

The first and fourth pages are only reproduced as pages 2 and 3 contain general conditions of supply.

Form "I" (a) is a data form which is filled up for each "telephone" system consumer. A great deal of the data will be omitted as soon as sufficient information has been collected. It was considered wise, however, to spend a considerable amount in labour to obtain very full information at the commencement of the introduction of the system.

Form M is a renewal of contract form, and the same remarks apply as to data.

The apparently laborious and expensive data are not vitally necessary to the adoption of the tariff any more than any statistics are vitally necessary in any department; at the same time one never knows when statistics may become of great value to an undertaking.

Each consumer is sent a copy of his agreement, and the following letter, signed by the General Manager, accompanies it. Also upon each renewal of the contract the other letter is sent.

Form "G." **Telephone: Paddington 771.**

Ref. No................... *App. No.*..................

Borough of St. Marylebone Electric Supply

Application for a Supply of Electrical Energy on the "Telephone" System of Charging.

To the Council of the Borough of St. Marylebone.
19 & 20 York Place, Baker Street, W.

The annual charge will hold good for each succeeding year provided you do not increase the number, candle power, and watts of the installation as per schedule.

(1) Full Christian Names and Surname and Present Address.

(1) I (or We) ____________________

(1) of ____________________
hereby require you to supply in accordance with the St. Marylebone Electric Lighting Acts, 1901 to 1904, Electric Energy on the "Telephone" system, at the premises hereinafter mentioned, for use with the installation therein on the understanding that the maximum No. of lamps is ______ and total candle-power ________ equal to ________ watts. And I (or We) agree and undertake to take and pay for such energy in accordance with the General Conditions hereto annexed, and that no alteration or addition in or to the installation, full particulars of which are specified below, shall be made without ______ days' previous notice in writing to you at your Electric Supply Offices, 19 & 20 York Place, W.

I (or We) agree that if the candle-power and watts as set out above are increased due to any alteration or addition in or to the installation, I (or We) will pay an increased sum, according to the Council's Standard Tariff of Charges as set out on page 25. If the installation is reduced, a corresponding reduction in respect of the amount charged shall be made by the Council.

Dated ____________________ 19

(2) Usual Signature. If a Company, must be signed by the Secretary or Manager on behalf of the Company. If a Partnership, by a Member of Firm for self and Partners.

Signed (2) ____________________

Witness { Signature ____________________
Address ____________________

____________________ Electric Supply Representative

Situation of Premises ____________________

Description of Premises ____________________

Purposes Electrical Energy is to be used for :—

____

Date by which installation will be completed ____________________

Name and Address of Wiring Contractor ____________________

____

TOTAL NUMBER OF LAMPS, ETC., PROPOSED TO BE INSTALLED.

Incandescent Lamps.		Arc Lamps.		Motors.		Other Apparatus.		(4) Total Requirements.					
No.	Watts	No.	Watts	Size	Watts	Type	Watts	Use for.	Watts Installed.	Watts Assessed.	Annual Charge. £	s.	d.
								Light ...					
								Power ...					
								Heat ...					
								Other Uses					
								TOTAL ...					

Note.—If any increase in the number of lamps, etc., is made, a fresh form must be filled up, signed, and forwarded to the Supply Offices. (4) Filled in at Supply Offices.

SCHEDULE OF CHARGES.

"TELEPHONE" (ANNUAL CONTRACT) SYSTEM.

This system is called the "Telephone" system of charging because it is similar to the charge for the telephone message rate service, viz., *an annual sum payable in advance plus 1d. per call.*

EXPLANATION OF TERMS.

The supply is given at a constant pressure of 240 *volts*. The amount of current or electricity flowing is measured in *ampères*. *Volts* multiplied by *ampères* gives the *watts*; 1,000 *watts* = 1 *kilowatt* (k.w.); 1 *k.w.* for 1 *hour* = 1 *unit*. A 25 *candle-power* metal filament lamp takes about ·135 *ampères* at 240 *volts* pressure, or 32 *watts* (240 × ·135 = 32), and will burn for 30 *hours for* 1d. at 1d. per unit (1,000 watts ÷ 32 watts = 30).

The large turbines at the Council's Generating Station have a power of 2,000 kilowatts each, and each will keep 60,000 25 candle-power metal filament lamps burning at one time.

A kilowatt (K.W.) is the electrical power taken by approximately 750 candle-power (c.p.) in metal filament lamps, say 30 lamps of 25 candle-power each, or 250 candle-power in the old-fashioned carbon filament lamps (*which it pays no consumer to use*), say 10 lamps of 25 candle-power each.

"TELEPHONE" SYSTEM: LIGHTING.

The annual charge (see schedule) is based on the number of lamps installed.

As an example the occupier of a medium size flat has about 800 watts installed for lighting (equal to twenty-five 25 candle-power lamps) and uses about 500 watts or sixteen 25 candle-power lamps (metal filament).

On the "telephone" system this consumer would pay £7 yearly in advance plus 1d. per unit for all units used. Special arrangements can be made for consumers wishing to pay quarterly in advance instead of yearly, at an increased rental of 10%.

The "Telephone" System of Charging for Lighting can only be applied to those premises using no other artificial light but electricity from the Council's mains.

SCHEDULE.

Watts.	Annual charge payable in advance. £	s.	d.	Watts.	Annual charge payable in advance. £	s.	d.
100	1	8	0	4,000	51	0	0
250	3	10	0	5,000	62	10	0
500	7	0	0	6,000	72	0	0
750	10	10	0	7,000	82	5	0
1,000	14	0	0	8,000	92	8	0
1,750	24	10	0	10,000	110	0	0
2,000	26	10	0	12,000	126	0	0
2,500	32	16	3	15,000	150	0	0
3,000	39	0	0	18,000	166	10	0
3,500	45	1	3				

A supplementary schedule will be supplied to consumers above 20,000 watts.

1 WATT = ABOUT ¾ OF A CANDLE POWER IN OSRAM LAMPS.
" " ¼ " " " CARBON FILAMENT LAMPS.

"TELEPHONE" SYSTEM: HEATING, COOKING, AND OTHER USES, &c.

NO INCREASE IN ANNUAL CHARGE FOR HEATING AND COOKING APPARATUS. ALL UNITS SUPPLIED FOR THESE PURPOSES AT ONE PENNY EACH.

Consumers must permit inspection to be made by the Supply Department at reasonable times.

HIRE OF METERS.

The charges for the hire of meters from the Council are:—

	s.	d.	
Meters up to and including 10 amp. size (2,500 watts) ...	2	6	per quarter.
Above 10 amps. to (and including) 25 amp. size (2,500 to 6,000 watts) ...	5	0	do.
" 25 do. 50 do. (6,000 to 12,000 watts) ...	7	6	do.
" 50 do. 100 do. (12,000 to 24,000 watts) ...	10	0	do.
All sizes above 100 amps. ...	15	0	do.

FORM "I" (a).

ST. MARYLEBONE ELECTRIC SUPPLY.

"TELEPHONE" SYSTEM OF CHARGING.

Consumer's Name *Ref. No.* *App. No.*

(1) *Address*

Description of Premises

(1) Fill in Residence, Flat, Shop, &c. If Shop, state class of trade.

DETAILS OF INSTALLATION.

		PRESENT.	FUTURE.
1.	Year ending	191	191
2.	Total watts installed for *lighting*	w.	w.
3.	*Convenience or inactive lights	w.	w.
	* These are lights in bathrooms, cupboards, lavatories, also larders and pantries, provided they are not used as sitting or bedrooms.		
4.	†Watts upon which annual charge is assessed ...		w.
5.	‡M.D. assessed at		w.
	‡ Residences, *deduct* (3). Business, &c., *include* (3). † Residences, 70 % of (4). Business, &c., 90 % of (4).		£ s. d.
6.	Annual charge, *Lighting*		
7.	" " *Other uses*		
8.	" " *Power*		
9.	" " *Total*		
10.	Total watts installed, all uses, including *Lighting* ...	w.	
11.	M.D. reading (*Lighting only*)	w.	
12.	" % to No. 2	%	
13.	Units used, 12 months		Estd.
14.	Average price per unit received	d.	d. Estd.
15.	Load factor based on actual M.D.	%	%
16.	Approximate amount of "*other apparatus*" than lighting	w.	w.

(2) PRESENT INSTALLATION.

(2) Use this form for all premises, making necessary alterations in each case.

All Electric? System of charging: (*a*) *Light* (*c*) *Heating*

Basement House? (*b*) *Power* (*d*)

SCHEDULE OF INSTALLATION (LIGHTING).

BASEMENT.

ROOM.	ACTIVE LAMPS.						CONVENIENCE OR INACTIVE LAMPS.						REMARKS.
	Plugs.	Points.	Total.	No. of Lamps.	Total c.p.	Watts.	Plugs.	Points.	Total.	No. of Lamps	Total c.p.	Watts.	
Passage													
(1) Stairs													
(1) Scullery													
Pantry													
Kitchen													
Sitting Room													
Bedroom													
Bathroom													
Lavatory													
Totals carried forward													

Room.	Active Lamps.						Convenience or Inactive Lamps.						Remarks.
	Plugs.	Points.	Total.	No. of Lamps.	Total c.p.	Watts.	Plugs.	Points.	Total.	No. of Lamps.	Total c.p.	Watts.	
Total brought forward													
GROUND FLOOR—Servants' Quarters.													
Passage													
Stairs													
Scullery													
Pantry													
Kitchen													
Sitting Room													
Bathroom													
Lavatory													
CONSUMER'S QUARTERS.													
Hall													
Porch													
Stairs													
Drawing Room													
Breakfast Room													
Dining Room													
Library													
Consulting Rooms													
Conservatory													
FIRST FLOOR.													
Drawing Room													
Bedrooms													
Landing													
Stairs													
Billiard Room													
Bathroom													
Lavatory													
SECOND FLOOR.													
Landing													
Stairs													
Bedrooms													
Bathroom													
Lavatory													
Totals carried forward													

Room.	Active Lamps.						Convenience or Inactive Lamps.						Remarks.
	Plugs.	Points.	Total.	No. of Lamps.	Total c.p.	Watts.	Plugs.	Points.	Total.	No. of Lamps.	Total c.p.	Watts.	
Totals brought forward													
THIRD FLOOR.													
Landing													
Stairs													
Bedrooms													
Bathroom													
Lavatory													
FOURTH FLOOR.													
Landing													
Stairs													
Bedrooms													
Bathroom													
Lavatory													
SUNDRY LAMPS.													
Coachhouse													
Yard													
Garage													
Lift													
Totals													

Annual charge of £ based on maximum demand of watts,
= % of watts installed.

(3) Use a line for each Motor.

(3) (**MOTORS.**)

H.P.	R.P.M.	Used for.	Remarks.

Total H.P. installed ... H.P.
" watts " ... w.
Annual charge ... £______

(RADIATORS, HEATING, COOKING, & OTHER APPARATUS.)

	Description.	Number.	Total Watts.	Remarks.
Radiators Ovens Irons				
TOTALS				

Annual Charge ... £

Watts ... ... w.

TOTAL ANNUAL CHARGE ... £

Signed

Occupation

Approved

General Manager.

NOTE.—If more than one pantry, bedroom, scullery, kitchen, &c., on each floor, put No. of rooms, and figures in columns opposite will be total figures, *e.g.* :—

	Plugs.	Points.	Total.	No. of Lamps.	Total c.p.	Watts.
Bedrooms (4)	4	16				

Account for the past twelve months for same premises ... £ s. d.

Estimated account on "Telephone" system :—

Annual charge ... ... £ s. d.

Number of Units at 1d. ... ... £ s. d.

Total ... ... £ s. d.

Saving ... ... £ s. d.

Increase ... ... £ s. d.

Form M. *Consumer's Ref*.................. *Application No*..................

Renewal of "Telephone" System Contract.

Name ____________________

Address ____________________

Description of Premises ____________________

	DETAILS OF INSTALLATION.			PRESENT CONTRACT.			FUTURE CONTRACT.
1.	Year ending			______191			______191
2.	Total watts installed for *lighting*			______watts			______watts
3.	Convenience or inactive lights §			______watts			______watts
4.	*Watts upon which annual charge is assessed ...			______watts			______watts
5.	† do. do. do. ...			______%			%

* Residences *deduct* No. 3. Businesses, etc., *include* it.
† Residences 70 per cent. of (4). Businesses, etc., 90 per cent. of (4).

		PRESENT CONTRACT.			FUTURE CONTRACT.		
6.	‡Approximate amount of "*other Apparatus*" than lighting	______watts			______watts		
7.	Total watts installed, all uses, including lighting ...	______watts			______watts		
		£	s.	d.	£	s.	d.
8.	Annual charge *lighting*						
9.	Annual charge "*other uses*"						
10.	Annual charge *power*						
11.	Annual charge *total*						
12.	Units used 12 months (last quarter estimated) at 1d.						
13.	Total Cost						
14.	Average price per unit received	______d.					
15.	Load factor based on actual M.D. (No. 16)	______%					
16.	M.D. reading of total installation	______watts					
17.	M.D. per centage to No. 7	______%					

§ These are lights in cellars, bathrooms, cupboards, lavatories, larders, pantries, provided they are not used as sitting or bedrooms.

‡ Nos. 6 and 2 should equal No. 7.

Approved ____________________ *General Manager.*	*Passed* ____________________ *Sales Manager.*
Date ______________191	*Date* ______________191

This form to be pinned securely to original agreement and data forms.

NEW.

Re "*Telephone*" *System of Charging.*

The "telephone" system of charging having been well taken up by consumers, it may not be out of place for me to remind you that, having adopted the system, the following advantages are yours:—

1. The most lavish use of electric light only increases the number of 1d. units.
2. Once the annual charge is paid, electric light only costs 1d. per unit.
3. It is not extravagant to use electric light freely on dark and dull days, and in dark places at 1d. per unit.
4. Waste of light in any direction—for instance, basements and servants' quarters—is only a matter of 1d. per unit.
5. Auxiliary uses of electricity, ironing, grilling, cooling, etc., can be effected by connecting the apparatus to any convenient lampholder or plug in any room at a charge of 1d. per unit, resulting in a saving in special wiring and meter rents.
6. Cooking and heating only cost 1d. per unit, at which price electricity is as cheap as gas for these purposes.

We have already received nearly £25,000 in annual payments, which illustrates the popularity of the scheme.

Yours faithfully,

General Manager.

RENEWALS.

Re "*Telephone*" *System of Charging.*

I am very glad to see that you have renewed your "telephone" system contract with us for a further twelve months.

In view of this fact I am led to believe that the system has given you satisfaction, and therefore I feel sure you may be inclined to consider an extension of the electrical service.

For instance, the electrical heater by simply turning the switch gives instant warmth without any of the noxious fumes and dirt inseparable from other systems of heating. Electric heating only costs 1d. per unit on the "telephone" system.

Again, the electric cooker is hygienic, clean, incredibly simple to use, and saves the butcher's bill, because the shrinkage in weight of meat is less with electric cooking than with any other method. The cost is 1d. per unit.

I enclose a list of other apparatus which may interest you.

If at any time you feel that electricity could be used to a greater advantage, both as regards cost and utility, in your home, I should be pleased to hear from you, and please bear in mind that expert advice is always at your disposal quite free of charge.

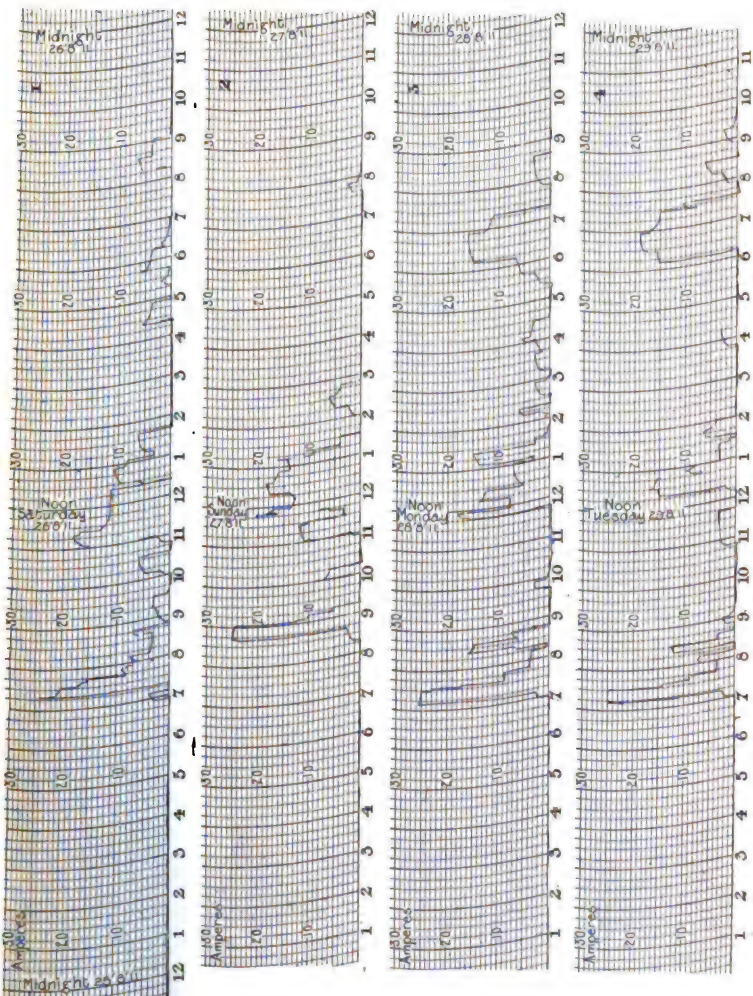
Yours faithfully,

General Manager.

APPENDIX II.

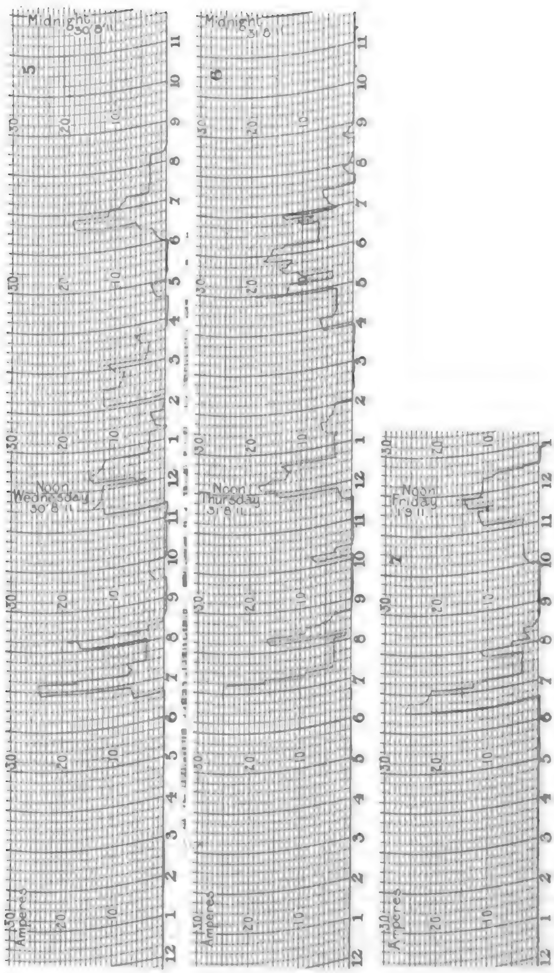
Ammeter Charts of Electric Cooking.

The following week's charts were taken at random; they are in no way selected.



The ammeter only records the current used by the electric cooker, which is a complete range and consists of oven, grill, warm chamber, and two hot plates. Maximum amperes when all circuits are switched on are 28 at 240 volts.

There are eight people in the house normally, and all food is cooked on the electric stove, no coal or gas being used; gas-heated water is used for baths and electrically heated water for all other purposes.



Saturday, August 28, 1911 (No. 1 Chart).—These people (who are quite unknown to the author) apparently have a hot lunch on Saturday, and rarely cook on Saturday evening. The same applies to Sundays (No. 2 Chart). The rest of the days in the week (Charts Nos. 3, 4, 5, 6, and 7) dinner is cooked in the evening.

It should be noted the maximum load is at breakfast-time.

These are summer charts, but in the winter the times of load will be similar, except that where there is a coal range the units will be less in winter than in summer. The heavy breakfast load is bound to come on both in winter and summer, because it will be easier for the maids to turn on the switches than light up the coal range.

Several of the more important guard-books containing similar records are in the room, and can be examined by members.

APPENDIX III.

Resident Tariffs in Germany.

From inquiries made by the author when in Berlin recently, it is apparent that British and American electric supply authorities have not much to learn from Germany as regards residence tariff making.

In Berlin they appear to favour no tariff but the flat rate, and charge about 5d. for lighting and 2d. for heating, requiring duplicate wiring and meters.

Differential rates do not seem to be favoured at all.

They appear to recognise to a certain extent their superiority, but cannot make up their minds as to the correct basis of the primary charge.

The German is naturally a methodical person, and likes to be mathematically correct, thus he prefers a system of charge by which he can measure a fraction of a unit, to a system part of which he frankly says must be guesswork. He fails to appreciate the fact that differential tariffs charge the consumer immeasurably nearer the actual cost of supplying him (even assuming that half the tariff is guess-work) than any flat tariff can possibly approach.

The high rate of 2d. per unit in Berlin does not permit of much heating business being obtained, although the cost of gas is considerably higher than in London.

On the other hand, the electric heating and cooking factories there were full up with work, and in one case a very large extension of the factory was being made. It was stated that the sudden increase in demand came about 12 months ago, practically the same time that a big increase in this class of work began to be felt in this country.

The German manufacturers were much more optimistic as to the future of electricity for heating than the electric supply people, and judging by the amount of money that is being sunk in the business, it is obvious that the former have faith in their convictions.

The author came to the conclusion that in domestic tariffs and electric heating and cooking, Berlin is certainly not ahead of London.

APPENDIX IV.

(*Copy of Report to Electric Supply Committee, St. Marylebone, and adopted October* 25, 1911.)

JOHN STREET DWELLINGS.

It is now a year since we commenced supplying these dwellings on the basis of a fixed sum per week, with no meters other than a master meter to check the whole consumption.

The results are such as to warrant a reduction in the charges per lamp per week, the 25 per cent. reduction in the price of osram lamps also helps materially in this direction. At the time the charges were fixed the smallest osram lamp obtainable was 25 c.p.; there is now available a 16-c.p. lamp, which is sufficient for bedrooms and will enable us to offer lower prices.

All new osram lamps, being wiredrawn, are much stronger than the old ones.

The total revenue for the year was £40 18s. 2d.

We estimated a year ago that £18 2s. 6d. would be required for lamps and sinking fund charge.

Deducting this sum from the total revenue leaves £22 15s. 8d. for current—2,006 units were used, so that we obtained 2·725d. per unit. On our standard rate of charge we should have received 2·842d., so that we have obtained practically our normal price per unit and have avoided the cost of meters, which would have doubled the installation cost.

Against the estimated sum of £18 2s. 6d. for lamps, depreciation, etc., we actually spent £3 18s. 9d., leaving £14 3s. 9d. to meet sinking fund charge. The installation cost £86 9s. 5d.

The present charges are :—

(*a*) 7d. per week per 25-c.p. osram lamp in living-rooms ; and
(*b*) 5d. per week per 25-c.p. osram lamp in bedrooms (provided they are not used as living-rooms) and alternative to (*b*).
(*c*) 3d. per week per 8-c.p. carbon lamp in bedrooms.

The proposed future charges are :—

(*a*) 6d. per week per 25-c.p. osram lamp in living-rooms.
(*b*) Alternative to (*a*), 5d. per week per 16-c.p. osram lamp in living-rooms.
(*c*) 4d. per week per 25-c.p. osram lamp in bedrooms (provided they are not used as living-rooms).
(*d*) Alternative to (*c*), 3d. per week for 16-c.p. osram lamp in bedrooms (provided they are not used as living-rooms).
(*e*) Alternative to (*d*), 2d. per week per 8-c.p. carbon lamp in bedrooms (provided they are not used as living-rooms).

RESIDENCE "TELEPHONE" SYSTEM RENEWALS.

Averaged Results at October 19, 1911.

	Number of Consumers.	Lighting. Watts.	"Other Uses." Watts.	Actual Maximum Demand. Watts.	Per Cent. to Total Installed. Watts.	Load Factor. Per Cent.	Average Price. Pence.	Units Used. Number.	Average Total Bill. £ s. d.
(1) Under 1 k.w. ...	54	589	1,090	1,598	98·0	6·25	4·58	772	14 14 7
(2) 1 to 2 k.w.... ...	27	1,408	1,959	2,538	79·0	9·20	4·23	1,776	31 6 0
(3) 2 k.w. upwards ...	18	3,072	1,227	3,763	80·7	8·10	3·97	2,608	43 2 8

The effect of these reductions will be, of course, to decrease the figure of £14 3s. 9d. probably by about a third, but it has to be remembered that the cost of installation wiring per tenement instead of being £2 19s. 7d. as at present will decrease to £2 8s. 8d. when they are all wired (we only have about half the tenements wired at present). Seeing that the dwellings belong to the Council a long period can be safely allowed for depreciation of the installation, especially considering that the cost is met as the money is spent and no loan raised. The life of the installation can be put at 20 years, as the work is most substantial.

I do not see any reason why we should not approach the owners of other similar tenements provided they are substantial people and the buildings are well put up, in order to see if they will agree to similar arrangements under a long term contract, properly drawn up to secure our property.

It would be an excellent investment to put, say, £1,000 to £2,000 of our surplus revenue in this class of work, but I do not favour raising loans for such purposes.

If we had some hundreds of such tenements we could afford to put a man on specially to look after them, which would materially assist in efficiency and enable us to nurse the business, which we cannot afford to do at present.

APPENDIX V.

The author has been requested to get out the table on page 411.

It is a summary of data collected from all residence renewal forms, that is, all residence consumers who have completed a year on the "telephone" system.

The table does not mean very much at present because it requires the data of some hundreds of consumers' installations of each class to give figures which would serve as an indication of results.

The table is corrected each month and in, say, two years' time will be of real value.

The chief reason that the figures are, if anything, a little misleading, is because the "other uses" watts have not in many cases been installed and used during the whole year. A consumer adopting the "telephone" system does not always install "other uses" watts immediately upon entering into the contract; he will perhaps start with a small amount of apparatus, and then heaters and a cooker come gradually, therefore the figures for load factor, average price, units used, etc., must be taken merely as a summary of results to date.

DISCUSSION.

Mr. Ruthven-Murray.

Mr. E. T. RUTHVEN-MURRAY: Many members of this Institution are inclined to look with disfavour upon papers dealing with the subject of tariffs and even to regard them as quite unnecessary, but those of us who are actively engaged in supplying and selling energy feel that there is no matter we have to consider which is of more vital

Mr. Ruthven-Murray.

importance to the industry, especially in view of the enormous developments we all expect to take place in the use of electrical energy, more particularly by domestic consumers, for what the author calls "other uses." Both at the end of his paper and in his opening remarks the author has invited criticism. I am sorry that on this occasion, though ready, I am not in a position to offer much constructive criticism on this paper, and must therefore limit myself to criticising the proposals he has put forward destructively. The author says, "No tariff is theoretically sound which does not differentiate between the two sets of variable costs, and which does not charge the consumer separately as to his standing costs and as to his running costs." It is equally true that an unsound tariff cannot be converted into a sound one just by the simple expedient of differentiating between those two costs, and I wonder whether the two-part charge of the telephone system does not constitute its only claim to soundness. The author has boldly introduced the factor of expediency into his tariff-making, which I think has weighed more with him than any other factor, since he points out there is no ground, except expediency, for making a reduced charge for any supply used during the peak in addition to other times. There is no other justification for supplying energy for "other purposes" at a flat rate of 1d. per unit. Briefly, what he does under the telephone system, and he tells us so quite frankly, is to put the whole of the standing charges on the lighting business instead of dividing them up between the lighting and the other uses; he charges the lighting consumer £14 per kilowatt, or rather 70 per cent. of £14 per kilowatt, for lighting only, and having charged this allows him to make an unlimited demand for other purposes without further payment towards the standing costs. That seems to me distinctly dangerous, because when the demand for cooking increases to the extent most of us anticipate it will very shortly, many consumers now taking, say, half or three-quarters of a kilowatt, will put in cooking apparatus, taking up to 2½, 3, and perhaps 4 or 5 k.w., and in view of this probability I think it essential to assess consumers on the basis of their actual demand, or at least their demand over peak-hours. Mr. Seabrook says: "It cannot be said that any hardship is thus imposed upon lighting consumers, because the 1d. units are available for any one who likes to use them." But, as we well know, nowadays people are none too ready to appreciate or value benefits provided for them partly and often indirectly at their own cost, and it may be that these 1d. units for other uses which Mr. Seabrook wants to force on his consumers will be looked on with suspicion by them. Then he says, "The principle of basing the charge for additional output on the cost of additional output was insisted upon and firmly established at the Local Government inquiry at West Ham in 1909." I should like to ask, How does he arrive at the cost of additional output, and how has he satisfied himself that it is remunerative to sell energy under the proposed conditions at 1d. per unit? The capital costs at Marylebone are comparatively high, and if it is necessary or even expedient

Mr. Ruthven-Murray. to charge the lighting consumer £14 per kilowatt of demand it must be necessary and justifiable to make some charge for the demand for other purposes. With regard to the author's characteristics of a sound residence tariff, I have come to the conclusion, after carefully considering his five essential features, that the telephone system fails to comply with a single one of them! No tariff can be characterised as an ideal tariff which, firstly, makes it necessary to assume the honesty of the consumer; secondly, which neglects to take account of the load factor of the consumer, or at any rate the demand during the peak; thirdly, which renders necessary details of the installation and purposes for which the supply is used; and, fourthly, which necessitates the invasion of the consumer's premises either to examine the consuming devices, to measure the cubic contents of the rooms, the number, or candle-power of his lamps, or indeed for any other purpose whatever. We ought never to need to go inside the consumer's premises at all. The author said some people might be inclined to think he had been too hard on the flat rate per unit charge. He says the flat rate "assumes that all consumers require the same proportion of units to their maximum demand, which is unsound and theoretically indefensible." But that is precisely what he does with his telephone system. It would not be so if he were considering lighting systems only, but since he takes no account of the maximum demand, for the other uses to which energy is put he is doing exactly what he says is so wrong in the case of the flat rate supply. Among his characteristics he says the tariff should be as simple as possible, and I entirely agree, but from the inquisition to which a telephone tariff consumer must be subjected as evidenced by the forms included in the appendices to the paper, there is nothing very simple about this tariff. The fact that it is called the "Telephone System" is said to help matters. I do not know why it should. There are probably far fewer telephone users in this country than there are consumers of electricity, and it cannot help an intending consumer to understand these charges to tell him he will pay in the same way he does for his telephone. Very likely if he had a telephone he would be paying on the unlimited scale, and therefore would not see the analogy. No, the undoubted success of the telephone system in Marylebone is due to the excellent and energetic sales department, and nothing else. On page 384 Mr. Seabrook refers to an account of the Illinois Electric Convention,* where it is stated that the committee on rates finally took up the differential rate, which, in general, is the form advocated. It was the unanimous conclusion of all who had studied the subject of rate-making that rates, if equitable, must bear a definite relation to load factor." Then he says, "In both countries"—that is in America and here—"the reason why tariffs on these principles make such little headway is the same, viz., the difficulty in applying those principles in the form of a simple tariff." I think every single one of us agrees, but that is really no reason why we should adopt an imperfect tariff which

* *Electrical World*, vol. 56, p. 1,036, 1910.

is not based on sound premises. The very adoption of the Norwich system and the telephone system with all their faults shows how eagerly a sound and simple tariff is sought after. I believe it to be possible to formulate a tariff which is excessively simple, fundamentally sound, and which will be, as Mr. Seabrook claims his tariff is, a good business getter. Mr. Ruthven-Murray.

Mr. G. WILKINSON: The primary object of this paper is to explain what the author calls the telephone system. The name is new; the system is old. The only difference between the system as propounded by the author and the one that I have used for years is that he gets fat prices where I get rather thin ones. Mr. Seabrook surveys a number of systems of charging, and amongst others he brings in the current-limiter system. He says, on page 383: "A 'limiter' spoils it on account of increased capital cost, which the system is mainly designed to avoid." He says they cost nearly as much as meters, and that it is far better to put a meter in and leave the limiter out. This is not so; the price of a meter would buy at least two limiters. Again, I think he quite loses sight of the fact that a limiter has no shunt loss, whereas the best alternating-current meters we can buy have at least 2 watts loss in the shunt, which at 1d. a unit amounts to 1s. 2d. a year. On page 389 the author again criticises the contract demand system, and sets forth his objection as follows: "The originators of the system do not seem to mind if 'other uses' are barred." The limiter system, such as was propounded both in London and Leeds in 1909, is a system intended mainly for artisan's dwellings, and we know perfectly well that in such dwellings all the "other uses" are fully met by the kitchen fire, and once a week or once a fortnight by what we know in Yorkshire as the set-pot for washing. On page 392 the telephone system is set out in some detail, and I find that the primary charge is fixed at £14 per kilowatt. The early part of the paper seems to bear the interpretation that the author in adopting this telephone system is conferring a distinct benefit and favour upon the consumer. Really the matter is the other way about, because he at once secures his standing charges and, I should say, a substantial amount to spare in the shape of profit. The author fixes his capital charges at £14 per kilowatt based on 70 per cent. of the lights installed, and certain allowances for convenience lights; this is a gilt-edged price. The price I have had for years has been £9 per kilowatt standing charge, not based upon an estimated 70 per cent. load factor, but based upon the definite reading of a demand indicator. On page 393 the author says: "Maximum demand indicators are used in all but small installations, and are put in circuit with the whole installation —lighting and 'other uses'—not for charging purposes, but as a guide in noting the load factor of the entire residence installation." I should like to ask him what happens if the guide shows that the guessed load factor is wrong, also how long he leaves the demand indicator in; because, as Mr. Ruthven-Murray has already said, we cannot say that every consumer is honest? We assess his lights, and immediately we are gone he may put in some lamps of higher candle- Mr. Wilkinson.

Mr. Wilkinson.

power. I know this is done, because I have discovered it myself. Where is his assessed demand as a guide then? Apparently the author puts a great deal of trust and confidence in the consumers, but his system appears to provide no check against alteration in the candle-power of the lamps. We now come to the secondary charge. The author ought to be very thankful indeed to get 1d. a unit, after getting £14 per kilowatt for capital charges. With regard to the "other uses" of electricity, we can give "other uses" of electricity only so long as our services and mains will carry the current required for those other uses without undue drop of pressure. It is a large house to-day that takes a maximum demand of 1 k.w. for its lighting requirement; and if we take the latest cooking stove, such as would be required for a house of this size, we shall find the maximum demand for such a stove is something like 5 k.w. Again, in a house where they can afford an electric cooker, and can afford to pay for electric cooking, they will have some radiators—I should say they would have at least three, taking, say, a unit apiece. Therefore we have a house capable for its lighting and "other uses" of imposing a demand on the supply company of 9 k.w., which is entirely beyond the capacity of the service cable, meter, and accessories. Again, the mains will be quickly loaded up by cheap units, and we are then faced with further heavy capital outlay. Thus Mr. Seabrook will be compelled to put on the capital charge of £14 per kilowatt for "other uses" which will at once destroy the economy of the whole arrangement. I should like him to follow this up and tell us something of what he proposes to do when that time arrives. The same thing applies to the generating plant. He will want more plant, and then there will be still further capital charges imposed. These are real difficulties which we have to face; we do not meet them now simply owing to the fact that the electric cooking apparatus is very expensive, and people cannot afford to put it in. We lay down mains for lighting, and then ask people to take for "other uses" amounts of current which, taking the fair example I have previously given, and allowing a diversity factor of 50 per cent. for "other uses," calls for 4½ k.w. per house for "other uses" against 1 k.w. for lighting. How can we possibly supply cheap units for "other uses" to this extent? I say we shall get very quickly to the point where extra capital outlay will have to be incurred, and then we will have to put on another £14 per kilowatt. I do not mean to say in raising this material point that it is one that cannot be dealt with. It will be dealt with, and successfully dealt with, but it cannot, so far as my judgment goes, be dealt with on the lines in vogue at the present time, that is, by adopting cookers and heaters as they are on the market to-day.

Mr. Wright.

Mr. ARTHUR WRIGHT: It is very difficult to criticise the operation of a system that has turned a very dead concern into a very live one. I think that Mr. Seabrook, whatever his system is, has given practical proof of its tremendous business-getting capabilities. In the old days it used to be very difficult to increase the business of Marylebone;

Mr. Wright.

nowadays it is somewhat difficult to get enough plant to meet it, which fact, I think, is sufficient testimony to the business-getting capabilities of the system. If I mention one or two little difficulties they must be in no way construed as antagonistic to this successful system. I wish to point out, however, that in my opinion, as has been expressed by Mr. Ruthven-Murray, the paper indicates too strong a tendency to give wide discretionary powers to the assessing officials. I think it may turn out to be a little dangerous as the business gets larger to allow the assessing officials arbitrarily to determine whether lamps are decorative or useful, and I cannot imagine that this arbitrary assessing can go on without leading to some abuses; that is the real difficulty of basing the standing charges on the installed capacity. Obviously it should not be on the total installed capacity, and yet where are we to draw the line in a drawing-room or hall, for instance, between the decorative lamps and the useful lamps? It must ultimately come down to some better method of assessment than the average convasser's idea of what is decorative and what is useful. The next point I think Mr. Seabrook has omitted in his system is, that there is no provision made for what we call commercial discount. Probably most of us now realise that one of the greatest factors in the reduction of cost is the quantity of electricity taken or produced. In this system, although it is applied chiefly to residential classes, there is no suggestion of a discount given for a large quantity. I think that such a discount is absolutely necessary. Everybody is entitled to a discount in consideration of taking a larger quantity than the average. We all know that to-day the reduction in costs that has been going on is due to the enormous increase of the quantity consumed; in fact, this increase of quantity has had more effect in reducing costs than has the improvement of load factors. I think an addition of some form of commercial discount would be a benefit to Mr. Seabrook's system. With regard to a small house lighting, we must now recognise that the cost of supplying such houses with electricity is almost independent of the cost of producing the electricity consumed therein. Taking the average house, which demands probably not more than a quarter or one-third of a kilowatt, the cost of the electricity consumed in that house is practically nothing compared to the service charges, looking after that customer's account, interest on mains, clerks' salaries, and time devoted to collecting the accounts. Therefore it seems to me as if, when a consumer's demand is below one-third or half a kilowatt, it is a mistake to charge on the kilowatt-hour basis; it ought to be somehow on the lamp or house basis, and that is why I think the annual lamp contract system is sounder if abuses can be checked by either a limiter or some other form of control. It is really absurd to charge by units in a house where the cost of the electricity consumed in the house is not 5 per cent. of the total cost of looking after the customer. I hope the author will be able to devise some method of tackling this class of property which, by the by, is the great bulk of the property left yet to be obtained.

Mr. Baker.

Mr. C. A. BAKER: I propose to criticise this paper from the point of view of the consumer, being in my official capacity probably the largest consumer of electricity in the world for lighting purposes: the County Council consumes in its public offices, fire-stations, stores, institutions, and schools something like 2¼ million units per annum, of which 1½ million units are purchased and the remainder are generated. In purchasing the 1¼ million units electrical energy is taken from 27 out of the 28 electric supply undertakings in London, and I come in contact with all the various tariffs, amongst others the telephone tariff at St. Marylebone, but it has never proved possible to adopt it. Mr. Seabrook has warmly recommended that system to me, but a simple calculation has shown that the standing initial charge is so very heavy that without any 1d. per unit added the cost is heavier than under his maximum demand system, with the recognised advantage of 25 per cent. rebate to large consumers. We all know that Mr. Seabrook has a very heavy millstone round his neck in the way of idle capital at St. Marylebone, something like 1⅓ million pounds; the interest and sinking fund charges on that capital is about 2d. a unit on his present output, if therefore he sells energy to one consumer—or for one purpose—at a gross rate of 1d. a unit, somebody else—or some other purpose—has to pay the other 1d. in respect of capital charges alone, apart from the works costs; apparently the lighting consumer desires to use the electric light notwithstanding the unfair burden put upon him; but for a tariff to be equitable all the consumers should be debited with a fair proportion of those capital charges. Of the London supply undertakers I find that 26 quote a flat rate tariff, 13 a maximum demand rate, 11 both, whilst only one relies entirely upon a maximum demand system. The author adopts the very wide term of "expediency" as his sole reason for departing from a maximum demand tariff, and he then endeavours to justify his action because it is expedient, whether it is lawful or not; for example, he gets £14 paid down by a householder at the beginning of some contract term—he actually says that his receipts are £25,000 a year in that way—I should like to know whether the whole of this sum comes from private residences. Then he states that if the consumer goes away he does not return any of the money. Now, supposing that the consumer has not used at least 420 units, it is not lawful for the author to retain the money originally paid, because his Act of Parliament compels him to supply electricity to anybody who wants it at a price not exceeding 8d. per Board of Trade unit.

With regard to "flat rate per kilowatt of maximum demand" the author finds that is not quite suitable for general purposes, and so far as his remarks apply to this country where coal is used at the generating station I agree, but in Lombardy a great deal of the energy generated by water-power is supplied in the villages for lighting purposes on this tariff system at something like 15 francs per lamp per annum, which is quite a satisfactory arrangement, because the length of time that the lamps are used does not matter very much: the con-

sumers have, however, to buy their own lamps. Mr. Seabrook states that he provides renewal lamps without charge. I think on that point he is wrong, he should make people pay for the lamps when worn out. As to the electric lighting of the tenement-rooms referred to, far too much light is provided and far too much money is charged for it. Where a few people are using a room they do not require a big light, because each one can go near to the light and so make the best use of it; a big lamp is not wanted: the annual cost is 37s. per lamp installed. I note from Appendix IV. that the prices are being reduced. Many of the streets of Marylebone are now lighted with incandescent lamps, burning probably about 4,000 hours per annum; I should be interested to know what the charge for the public lamps is as compared with the private lamps at 37s. With regard to tariff systems generally, I made at the outset some remarks on the author's plea of "expediency"; I think that a far stronger case for a simple tariff can be based on the solid foundation of "averages." Everything should be worked out on that basis. Insurance companies employing many millions of capital do the whole of their business on the basis of averages. Fifteen years or so ago when the maximum demand system was introduced experience was lacking as to the relative value of different classes of consumers, but with the data since collated there is no good reason at the present time for employing any tariff system depending upon two factors for residence lighting. The ordinary flat rate tariff—adopted, as I have pointed out, by 26 out of 28 London supply authorities—is convenient and depends only on one factor—a very great advantage to every consumer. No matter how clever a consumer may be or how much he may be interested in his demand indicator, his consumption invariably depends so much upon subordinates, or perhaps upon independent supervision, that a flat rate system is by far the preferable one, because it depends entirely on one simple factor, and economy can be secured under that tariff system by regulating the number of hours the lamps are alight; any result dependent upon two factors is more difficult to determine from moment to moment, and as a result the maximum economy cannot always be secured. The telephone system, like many of the other systems of tariff mentioned by the author, has the very grave disadvantage of inspection by officials—a process to be avoided where consumers' private residences are in question. Again, as to the initial charges it will be interesting to see how far these charges will be reduced as 16-c.p. lamps replace 25-c.p. lamps on 240-volt circuits: the problem of making both ends meet under the load of the millstone referred to becomes ever more perplexing. Mr. Baker.

Apart from the tariff system, the people who have electricity to sell should cut out all the objectionable clauses of the rules and regulations which they issue with a view to controlling the consumer. These regulations must, I am sure, ward off many consumers who naturally will not trouble to peruse them, whilst they are altogether unauthorised and are not worth the paper that they are printed upon unless they

Mr. Baker. have been approved by the Board of Trade; and I believe I am right in saying that none of the rules and regulations have been so approved —certainly 99 per cent. of them have not.

(*Communicated.*) It is interesting to note that the author in his reply states that the public lighting is charged on the maximum demand tariff, not on the telephone system.

Mr. Cooper. Mr. W. R. Cooper: I do not understand how any station engineer can suggest that the subject of tariffs is not important. Selling is really quite as important as efficiencies. Having advocated the Hopkinson system in a paper which I read before this Institution, I am glad to see that the system is making headway. I cannot comprehend how anybody can advocate a flat rate system at the present time, or how they can say that the business of lighting, heating, and cooking can be carried on by means of one flat rate; it is practically impossible. I think there is no doubt that the Hopkinson system in some form or other is the correct system to go upon, and in my opinion it does not much matter what precise form it takes so long as the consumer is satisfied. I notice on page 391 that the author apparently objects strongly to a charge of so many units per quarter at a higher price, and regards this method as essentially different from the telephone system, and as displaying a want of perception of the basis of tariffs. I must say that in this I do not agree with Mr. Seabrook. Whether the charge for lighting is made as one lump or on, say, the first 100 units per quarter, it is still the Hopkinson system. The main thing is to have the form so that the consumer is satisfied. I am a little surprised that Mr. Seabrook's consumers part so easily with their money; this is certainly a testimonial to his system, but I doubt if consumers in all parts of the country would take to this reversal of the usual custom so readily. Of course such a tariff is not always accurate, but it is much more important to get business than to have any accurate tariff. I am rather surprised that any engineer should in these days talk of a really accurate tariff; it is not worth troubling about. The chief thing is to get the business on an average paying basis. There may be errors, but the errors are likely to cancel out. I am also glad to see that the author has a certain amount of faith in human nature. Some station engineers are very much afraid of being swindled by one or two consumers, but it is better to run the risk of a small loss through dishonesty rather than not to obtain the business. There are two or three questions I should like to ask. Firstly, how often does the author make an inspection on the telephone system? Secondly, what happens if a consumer changes to metal lamps? Does he get a reduction, or does the author maintain his annual charge? Then on page 410, in regard to John Street dwellings, is not the difference in the charges for living-rooms and bedrooms rather small? Perhaps in those flats the bedrooms are used more or less as living-rooms. Finally, I cannot help thinking that the author has misunderstood Mr. Lackie's tariff. Surely the maximum applies to the estimated lighting load alone and is unaffected by appliances for heating and cooking.

Mr. A. H. DYKES: Every tariff that has ever been proposed is probably the best one for some particular station. The tariff must depend entirely on the nature of the district and the people who are going to be served. It depends also, of course, on the machinery we have in our station. It is affected by whether we are supplying alternating current or continuous current; by whether we have big storage batteries, and so on. A discussion on tariffs is always interesting, because although possibly no station engineer will approve of the exact tariff which is set before him, yet in the discussion he is bound to learn some points which will be of assistance of him. The author divides the possible tariffs for residence tariffs into a number of classes starting with the flat rate. I hold that the flat rate is only permissible if we can store electricity very cheaply, and if we have no expenses outside the station. Granted those two things then a flat rate is permissible, otherwise it is absurd. We have to offer it, owing to the Acts and to the price that is inserted in the Schedule and the Orders; but the best thing to do is to make it as high as possible, and then most people will go on to some other more satisfactory tariff. The next system, which is the most general one of all for the moment, is some modification of the Hopkinson system, which is theoretically the most perfect one of all. The original Hopkinson system was based on a fixed charge depending on the total number of lights connected, and a small charge to cover the running expenses. Obviously the effect of that was to reduce the number of lights put in, and Mr. Wright soon introduced his well-known modification in which the price depended not on the total number of lights installed, but on the maximum in use at once. I need not go into the reasons why that system is not as largely used now as it was some time ago. When in 1908 Mr. Handcock and I read a paper on the same subject of tariffs we put forward the suggestion that the maximum charge instead of depending on the reading of an instrument which varied from quarter to quarter, should be based on a fixed charge settled in advance. I should explain here that we were dealing then more particularly with lighting stations, and the "other uses" to which the author has referred so much to-night were not then so well known; and there are still a great many stations where the other uses are not anything like so important as they are in Marylebone. We therefore advocated that a limit indicator of some sort should be fixed which would indicate when the agreed contract demand had been exceeded, but we stated that although we recommended a limit indicator being used it was obvious that this could be dispensed with and the contract demand settled by the station. The telephone system is the contract demand system with the limit indicator left out, with the difference that we were not as generous as the author in respect to current for "other uses." We did not suggest that all the "other uses" current should be given at 1d. a unit whether it came on the load or whether it did not. We were under the impression that if a load came on the peak it should bear its fair proportion of the standing charges, not as much as the lighting load

Mr. Dykes. because it had a better diversity factor, but it should bear a proper proportion.

As has been pointed out two or three times to-night, and as Mr. Snell pointed out some years ago in his paper, we have only to get a sufficient number of 1d. units to swamp the lighting load, and then additional plant and additional mains have to be put down to meet these 1d. units. The author deals with that difficulty. I am interested in looking at the table on page 411 in seeing how it works out. It will be noticed that the lighting watts installed are 589, and the "other uses" watts are 1,090. It is probable that the load factor of the "other watts" is better than that of the lighting watts, and therefore that the units used for other purposes are greater than those used for lighting. Therefore if the average price is 4·58d., and the greater part of those units are 1d. units—it is obvious that a rather high price is being paid for the lighting units—I should say something like 1s.—and that is where the author's system scores. If we can sell a nice number of units at 1s. we can afford to sell some at 1d.—it is good business. I think this system of relying, as Mr. Seabrook does, on inspection and the good faith of the consumer, is not one which is likely to become very general. Inspection must be costly. The consumers will change their lights, and there are no means whatever of knowing, once their contract demand or their telephone charge has been settled, that they will not double their candle-power the day after. I am perfectly certain it will not work in small country installations, where everybody knows everybody else's business, and where they will discuss whether their particular lights are convenience lights or whether they are not. I do not think that will be a solution of the problem. For purely lighting loads, I still believe that the contract demand system with a limit indicator is very hard to beat. It is simple. The consumer merely has to fix what he requires; he settles once and for all what his demand is, and if he exceeds it he does so knowingly. The rate is then put up, and he pays an increased rate accordingly. After he has settled his contract demand he can use as many units as he wants at a 1d. a unit. On the other hand, I freely admit it is a little difficult when we come to stations like Mr. Seabrook's where the "other uses" are important. I am inclined to think that possibly in the future we shall hear a great deal more of the two-rate system of charging, where one rate is charged during certain hours of the day and another rate during other times of the day. I am trying that now in one or two instances, and, like the author, I am accumulating facts and data. At present I am inclined to think that for these mixed systems there is a good deal to be said for the two-rate system. When, however, we come to the smaller class of consumer which, as Mr. Wright said, constitutes the chief field that is now open to us, there the only real system is a fixed charge depending on the number of lamps. It is really the Hopkinson system.

With small consumers, where we shall be forced to include the wiring, and where the capital charges are increased beyond what they

Mr. Dykes.

are when we are supplying the ordinary consumer, the additional charge, if they take a few extra units, is practically nothing in comparison with the standing charges, and therefore we are practically forced to a fixed rate. Some time ago Mr. Handcock and I set ourselves this problem: Is it possible to go into a district in London which is served by the strongest gas company probably in England, where gas is active, where they are doing everything they can, and where up till now it has not been considered worth while running electric mains although they pass close by—can one go into such a district and prove that electricity will compete with gas? That is a business proposition which must appeal to all of us, and in answer to Mr. Seabrook's request to-night, I am pleased to be able to give you a few figures of the operation of the company alluded to by him.

It is not a big concern; but the results obtained have been interesting. It took two areas—one in Bermondsey and one near Waterloo, both poor districts and both served by the South Metropolitan Gas Company—and set to work to see whether in those places electricity could compete with gas. Obviously, as Mr. Wright said, it is not the cost of producing the electricity that has to be borne in mind; the company knew it could do that at the proper price. It is the other expenses, the cost of dealing with the consumer, which kill you. Obviously if an expensive service is going to be put in under a London street to every house; if a meter is going to be installed and small bills sent in, and at the end of the quarter the amount cannot be collected, it is impossible to compete with the gas company. What was done was this: it was decided that the proper way was to approach the owners of property and say to them: "We will wire the houses for your tenants if you will give us permission as a *quid pro quo* to run the wires along the front of your houses." They were thus able to put one service into a street, or a terrace of houses. A concentric wire was then run along the outside of the houses, which cost on an average 1s. 3d. per yard run erected, which compares very favourably with the cost of opening up a yard of London street and putting down a main underneath it. They abolished the meter, and used a simple form of service into the houses consisting merely of a single-pole fuse. The cost of that service, including testing the installation, putting in the lamps, and generally talking to the consumer comes out to something under 10s. a service. The company did not put a long document before the consumers which would have frightened a lot of them, because they were supplying small people living in small houses with about five rooms, mostly with a lodger on the top floor; they did not have to enter into any definite agreement at all. The company relied on the fact that once they had wired the houses, electricity would be cheaper than gas, and all they were asked to sign was this form: "I request you to provide the above-mentioned lights in accordance with the terms set out on the other side which I accept, and I will make the payments to you weekly in advance." On the other side it says: "The company is prepared to arrange for the fitting up of private houses for electric lighting, including the first

Mr. Dykes. lamps, and for the supply of electric current at an inclusive weekly rental of :—

	Summer Months (April to September).	Winter Months (October to March).
	d.	s. d.
One light	5	0 5
Two lights	6½	0 8½
Three lights	7½	0 10½
Four lights	10	1 2
Additional lights, each ...	2½	0 3½

The light may be used as long as required, on the condition that it is used reasonably and not wasted. The selection of the lamps shall be left to the company, who will in all cases where possible arrange so as to light each room with one lamp. The company will arrange for keeping the installation in good order free of charge except in respect of breakages or damage, which must be borne by the consumer, who must allow the company access to the premises for inspection or repair. New lamps will be supplied by the company on easy terms when required.—Special terms for shops." What is the result? I will take one street alone. There are seventy-two houses in that street, and gas on the penny-in-the-slot meter system had been installed in them by the most business-like gas company in London. The first main was laid there in June of last year, and to-day over half those houses are supplied with electricity, and they are coming on day by day. That is only one street, and what is more important still is that nearly every consumer who has started with one or two lights has ordered some more—they now have about four or five lights a house, one in the kitchen, one in the passage, one in the front room, and generally one in the bedroom. It was objected that people would waste the light. This has not been found to be so. It is not wasted because if the tenants waste the lights they burn out the lamps. It costs them more for lamps, and that has been well drilled into them. These people cannot afford to put down half a crown or three shillings for a lamp, so the company assists them in this respect—they hire a lamp for the term of its life. At the present time there are, roughly, 300 consumers on the books in that way, the houses all being wired complete, with simple fittings.

Mr. Moncrieff. Mr. K. A. SCOTT MONCRIEFF: In reading this paper I think we see Mr. Seabrook in a dual capacity. In the one hand he has the Hopkinson system with a slide rule for working it out, and in the other a sheaf of publicity documents labelled "Expediency." I do not think there is such

Mr. Moncrieff

a very great difference between a scientific system of charging and some of these points of expediency. There are many points that cannot be as clearly defined as the Hopkinson system, but which are, nevertheless, potent factors in determining the price at which we can supply. There is the question of the total output and there is the question of the diversity of the individual load (which is not fully met by the ordinary Hopkinson system, telephone system, or any such other). There is also the question of the loading on the mains. A great deal of the capital expenditure on the mains is influenced more by the length than by the sectional area, and if we get a good heavy load per yard on our mains it is almost equivalent to the advantage we get from a bulk supply. The author refers on page 378 to the typical case of a man who lives in his house all the year round and his neighbour who goes away for six months, and he says that the man who goes away for six months ought to pay a great deal more per unit than the other man. But if he goes away for six of the winter months the position is reversed, surely. In order to look into this proposal I have studied the returns of the London Municipal Undertaking, and I find we cannot get a curve based on the load factor and the selling price, nor on the total output and the selling price, nor on the capital expenditure per unit and the selling price. I think it is a mixture of the whole lot and perhaps one or two other factors of expediency. I should like to ask the author to more fully explain the point he makes with regard to the West Ham inquiry. I take it that what he means is this. If he has two consumers, A and B, he goes to A and secures him on a good paying rate, but what does he do when B comes along? He "dumps" the energy on him at a low rate because he is getting all his standing charges out of A. That does not seem to me to be fair, although it may be expedient. He has carried this system to Marylebone. A is the lighting consumer; B, upon whom he dumps the energy, is the other user—it may be in the same house, but still the other users are getting an unjustifiably low rate. I notice that the author makes a point of mentioning selling points. I think we are all too backward in that matter, but there is one point here which I think is not a selling point. He asks the Marylebone consumer to pay him in advance for a year five-sixths of his total electricity bill. I do not think that can be done in the majority of the districts of supply. But there is a selling point which the author does not bring out. He quotes £14 per kilowatt for 70 per cent. of the rated loading. He says to the man, "I will charge you only for 70 per cent., but I will give you 100 per cent." The consumer pays for it all the same. It seems to me to be fairer to say, "We will charge you," I was going to say, "£10 a kilowatt for your total lighting." It is really £9 16s., not very different from £10, but perhaps it sounds much less. The author has referred to the results he has obtained, and I thought it of interest to apply his tariff to the published results for 1910. I have taken his total kilowatts connected, some 20,000, and applied his telephone charge, which works out at £202,000, and a 1d. per unit on the 12,000,000 units

Mr. Moncrieff.

works out at £51,000 odd. The total is £253,400; but his receipts were only £165,000. The difference is £88,000, and that difference is the measure of expediency, the measure which shows how far short this maximum demand system of charging falls when we really want to sell electricity. He cannot apply it to the full extent, and he has to reduce the amount he would get by some 30 per cent. It is a very big difference. I do not want in criticising to imply that the system is not a good one. I think there is a big field for it. It is a question between having a system of this sort, or some variation of it, or double wiring. There is no doubt that for heating and cooking we must have a lower rate. That can be met by the telephone system or by double wiring. There is something to be said for double wiring. If we get a small consumer taking, say, 240 watts, he has perhaps an auto-transformer installed, and if he puts on the humble flat-iron taking 400 watts it creates rather a consternation in the whole installation. Therefore, I think the double-wiring question will always be to a certain extent before us, whatever the standard of charging is to be. I observe that in the last paragraph the author refers to those optimists who think that some day we will get a very low flat rate that will cover everything. I believe our President is somewhat of that opinion, and I am a humble follower of his. I think in time we will come to a dead flat rate. We are getting fairly near it in industrial towns. There are towns where the total receipts for units sold are in the neighbourhood of 1d. per unit. Referring to the author's argument that there must be some peak loads, those peaks will be a very small percentage of the total maximum demand in the station, and I think that the capital value of those peaks will, therefore, be very much reduced. Having looked into it roughly, I am of opinion that with a capital expenditure of £50 per kilowatt and 28 per cent. load factor it may be possible to supply all round at 1d. a unit, and I do not think we are very far off those figures. We have not reached them yet in all cases; in some cases we have exceeded them, but I think they are well within our view. In conclusion, I think it might be a good plan for those of us interested in electrical supply to form an association inside this Institution to collect statistics and study these questions. Mr. Seabrook has laid before us a few statistics, but there must be many others that are available if specially asked for by the Institution of Electrical Engineers and not asked for by the general public. We all get circulars asking for information, but it is a different thing altogether if such a circular comes from the Institution. I think a good work could be done in that direction, and that supply undertakings, companies and municipal, would find it to their advantage to subscribe towards the cost of collecting such data.

Mr. Long.

Mr. F. M. LONG: As the author has referred to the Norwich system, which I was responsible for introducing, I would like to make a few remarks in connection with it. I would never claim that this system of rateable value as a basis is applicable to every place. I certainly do not think it would be applicable in Marylebone, nor could

it be applied probably in any seaside town. But for the majority of provincial towns of moderate size I think it has a very great many advantages in its simplicity, and in the fact that on the average it works out very well. There is no doubt that a system of primary and secondary charges is the right thing for private houses, but the primary charge should be a fixed charge for the particular house. Once it has been settled upon I do not think we ought to have to depend upon the honesty of the consumer, or that the consumer, on the other hand, should be liable to any penalties or pains if he wants to alter the lights in his house. The more freedom we can give to a man to use what he wants the better it will be. I consider therefore that the primary charge should be fixed in the first instance. Rather than base it throughout on the actual number of lamps connected, which is not an easy matter when convenience and decorative lamps are allowed for, I would prefer to take it upon the number of rooms, the size of the rooms being taken into account as well. The author does this to a great extent, because he does not omit decorative lamps until the number of lamps included in the charge amounts to 1 watt per square foot. I would make an assessment of what was required on a good average basis for lighting the house throughout, taking into account the number and size of the rooms, and base the primary charge accordingly which once made would not be altered, and the consumer would then be quite free to do what he liked. The figures that Mr. Seabrook obtains have been referred to as being very high, and they are certainly very much higher than we get in Norwich. £14 per kilowatt on 70 per cent. is equivalent to £9 16s. on the total connected. We only get something like £4 per kilowatt connected in Norwich charging 12 per cent. on the rateable value, but still we do very well with that, and the system is thoroughly satisfactory to the inhabitants of Norwich. We have something like 2,500 consumers who have taken up this system, which represents over two-thirds of the private houses supplied. That shows that it is really satisfactory, and I think it will be found in most provincial towns to be the most satisfactory basis of charging. Mr. Long.

Mr. J. A. B. Horsley: We hear much about the importance of the cost of generation, load factor, diversity factor, and so on, but not enough, I think, of the consumer's point of view, and that is, the price which he is prepared to pay for the service. I propose to give just a little information with regard to a tariff which the author dismisses in one sentence. In the station with which I am connected we have a very large proportion of quite small consumers, and we find that a slot meter tariff finds great favour with them. In 1907 when I went to Harrow we then had a total of 1,047 consumers, of whom 13 per cent. were supplied by slot meter. The slot meters were calibrated at 8d. a unit. Our load was practically exclusively a lighting load, and the bulk of the lighting was residence lighting. The average annual revenue that we obtained from all our consumers was £8 3s. per consumer. The slot meter consumers only brought in 26s. each. That, of course, was not satisfactory. I suggested a reduction from 8d. to 6d., Mr. Horsley.

Mr. Horsley. but objections were taken to that, on the ground that it might lead to complications with our ordinary quarterly account consumers, who were supplied on the maximum demand system at 7d. and 4½d. I then proposed and obtained the approval of my board to a modified slot meter tariff—I might call it a differential slot meter tariff. The meters remained as before, calibrated at 8d. per unit, but we offered a rebate at our quarterly collection of 1s. in 3s. after the first 5s. prepaid, on certain simple conditions, one of which is that the consumer lets us have notice before he leaves the premises. I find that tariff has several very useful qualities. Previously slot meter consumers apparently thought that it was not necessary to tell the supply authority when they left the house. Consequently when we did find out at the quarterly inspection that the house was empty, there was sometimes only the remains of the meter to collect. The landlords have a happy knack of leaving houses open so that anybody can inspect them! Then there are various other advantages. This rebate enables us to collect any small amounts that may be due for lamps supplied, or repairs, and that sort of thing. Also, the husband generally supplies the coins that go into the meter, while the wife gets the rebate! It takes a quarter or two to appreciate the merits of the tariff, but after the first rebate they like it very well. I should like to give you a few figures showing the progress we have made. For 1910 the average annual revenue from slot meters had increased from 26s. to 32s. 6d. each, while the total revenue from slot meters had risen from £174 to £550. The "slotters" then numbered 26 per cent. of the total consumers, while in 1907 they represented only 13 per cent. In 1907 we sold 5,200 units through slot meters; in 1910 we sold nearly 21,000 units, and the number of units sold through such meters is still increasing. Slot meters represented in 1907, 2 per cent. of the total lighting revenue and 1·38 per cent. of the total lighting units; whereas in 1910 these figures became 5·8 per cent. and nearly 5 per cent. respectively. The average price works out in this way: they pay 1s. 8d. per quarter for standing charges, and obtain all their electricity at 5¼d. a unit. That may seem high, but in view of the wonderful efficiency of the tungsten lamp consumers get good value for their money, and we find that we can compete with gas.

Discussion at Meeting of 18th January, 1912.

Mr. Highfield. Mr. J. S. Highfield: In designing a tariff for the sale of electricity or anything else it is essential to keep in view the object of the tariff. I take it that this is to extract from the consumer the largest possible revenue at such a price as will enable a profit to be earned which will prove attractive to the investor, so that fresh capital may be freely imported into the business. The price must not be so high that all that is earned is a large rate of profit. What is wanted is to sell a very large amount of energy, and to have a very large sum in the way of profit at an adequate rate. Unfortunately, owing to the fact that so

Mr. Highfield.

much electricity is sold under municipal management, the importance of a large return of profit on the capital employed is to some extent lost sight of, because capital is raised, not on the credit of the business, but on the credit of the rates; in any commercial enterprise this is a great pity, because it is the large size of the profit that attracts new capital into the business. We who are engaged in obtaining money from the public for the supply of electricity have to remember that on us depends to a very large extent, not only our own success, but the success of all the industries connected with us. For instance, the success of people who supply engines, dynamos, boilers, and so on, depends to some extent on the amount of orders we give them, and on the price we can afford to pay for the plant we buy. Consequently it is for us to see that we get from the consumer sufficient money to pay a decent price for the boilers and machines that we use in giving a supply to the public. I think that is the first object of any tariff. I would plead, in the first instance, for greater uniformity of rates. It is a most distressing thing that the rates in different parts of the country, and even in neighbouring districts, are so very diverse. It confuses the consumer, and it makes the business of managing a commercial undertaking very much more difficult. There cannot be any proper reason for this immense variation, not only in the rate of charge, but in the system on which the charge is based. For instance, in Acton there is a flat rate of 6d. a unit; in Hammersmith, an adjoining district, there is a flat rate of 3d., and in Willesden I believe the flat rate is 4d. or 4½d. All those are neighbouring undertakings, and there can be no proper reason for the immense difference in charge. The striking thing is that the success of the undertakings, that is to say, the success measured by the number of consumers connected, is very much the same in the three districts. I think it incumbent on every supplier of electricity when considering an alteration in the amount of the charge, that, before making any alteration, he should consider not only what the people round are charging, but the methods by which they are making the charge. At our last meeting a great deal of discussion turned on what I might call the scientific aspect of the tariff, that is to say, the theory that the charge made to the consumer should bear some relation to the cost of giving the supply. Admittedly, some consideration should be given to this matter. I would like to draw your attention to the financial conditions applying to gas, electricity, and water undertakings, because I think they are rather interesting. I do not pretend that the figures are absolutely conclusive, but I believe they are typical.

I have taken out the figures for about half a dozen of the largest gas, electricity, and water undertakings in the country, and altered them so as to give a constant return of 8 per cent. on the total capital employed, and I have arrived at the following result, which I think it will be agreed is very interesting. If we assume that £100 represents the capital employed in each of the three cases, the gross revenue for gas undertakings is £32, for electricity undertakings £13 10s., and for water undertakings £10. The costs are £24 for gas works, £5 10s.

Mr. Highfield.

for electricity undertakings, and £2 for water undertakings. The ratio of costs to revenue is 75 in the case of gas, 40 in the case of electricity, and 21 in the case of water. Now this, I think, clearly shows why it is a proper thing to charge for gas in proportion to the amount of gas taken, that is, by meter at so much a thousand cubic feet, because in this case the working charge is much the most important part of the total charge. In the case of water the working charge is a very small proportion, as these figures show. Consequently, while it is quite scientific to charge for gas at so much per 1,000 ft., it is also right to charge for water at so much per cent. on the rateable value, leaving the consumer to use as much as he pleases. It will be noted that electricity comes at an intermediate stage between the two, and therefore the figures provide considerable justification for the system of charge that the author calls the "telephone" system, where the charge is divided into a fixed charge of so much per quarter or per annum depending on the demand, and so much for the energy depending on the amount of current taken. This tariff was, in fact, so far as I know, first introduced by Edmundson's Electricity Corporation some eight years ago under the name of the "yearly contract system." We now call it the "contract tariff." It is quite clear, of course, that as the load factor on the electricity works improves by the use of heating and cooking apparatus the working expenses become more important in relation to capital expenses, and the figures of the electricity works will more nearly approximate to the figures of the gas works. Consequently, if we can conceive that the load factor on the electricity works will go up to something like 50 per cent. in the future, it is quite possible that the flat rate of charge at so much a unit will ultimately be the proper charge. But we have to deal with the present, and I think that for all our own purposes the telephone system, or what Mr. Seabrook calls the "Metropolitan" system—which really we call the "contract tariff" system—is probably the best solution. The flat rate makes it quite impossible to use cooking apparatus or small heating apparatus on the same wires as the lighting. Every day it is becoming more apparent that consumers want to use electric kettles, irons, and suchlike apparatus, and that they will not pay for the extra wiring that is necessary if a separate flat rate is charged. Therefore I am quite sure that the system of using a fixed charge, together with a low rate per unit, is the proper system to adopt. I do not mean to say that we should try to force our consumers to adopt this system—not at all. As long as they are paying us a reasonable sum per annum on a flat rate, I should leave them alone, but as soon as they want electricity for other purposes than lighting, then is the time to bring forward the contract tariff or the telephone system, which saves the cost of extra wiring, and if they like to use it, let them use it. I do not hold with the idea that the habits of your customers can be altered by any tariff. It seems to me that a tariff is simply made for revenue purposes; we want to collect so much money, and I do not think we can alter the tariff and make a man burn a light

Mr. Highfield.

in the middle of the night if he does not want to. Mr. Seabrook has criticised in a mild way the tariff that I prefer, that is the fixed charge, with 2d. as the charge per unit for a certain number of units until the amount paid equals the fixed charge, and 1d. for the additional units. It is a matter of argument, but I am very strongly convinced that the immediate charge of 2d. is useful, and for these reasons. It enables the fixed charge to be smaller than when a 1d. per unit obtains, and although some consumers do not mind a high fixed charge, I find the majority do. But the more important point is that 2d. is a perfectly proper price for the use of electricity for what I should call small purposes like small hot-plates and kettles. I think it is important to remember that the consumer does not know in the least what his bill is going to be. If we tell him we charge 1d. or 2d. or 2½d. a unit, he has no idea as to how much he is going to pay yearly. Therefore I attach no importance at all to the price of the unit, provided a smaller charge is not made in an adjoining area, and that the cost compares fairly well with other methods of doing the same thing. It is one of my grievances that so often neighbouring undertakings have reduced their prices when I do not think there is any reason for doing so. It is not very long since a large number of undertakings in London reduced their flat rate for heating to 1d. a unit; others did not do so. Yet I undertake to say that they put in just as much heating apparatus and obtained just as much business as the undertakings that reduced their prices. I do not believe for a moment that the obtaining of business depends directly and solely on the lowness of the tariff. It depends at least as much upon the energetic conduct of the business. The ordinary flat rate of so much a unit is, of course, far and away the most popular system in the country. People understand it. It is analogous to gas charges with which they are familiar; and Mr. Seabrook has, I take it, called this system the telephone system because he thinks it is like the method of charge for telephones. Whether that is of very much value to him in canvassing I cannot say, but I can quite conceive it would be so. Other rates of charging are the slot meter method and the flat rate per lamp method—that is, a fixed charge of so much a year for each lamp with no unit charge; the consumer can use as much as he pleases. I would like to say a word about my experience with these two charges.

I should like to hear other engineers' experience of slot meters, but my own is as follows. We have had several thousand slot meters erected in different towns in the country for a great number of years, and I can say that in the main the whole of that slot meter system has been a failure. The consumers, for some reason or other, put pennies in the gas slot meters, but they will not put them in the electricity slot meters. In London we have a number of slot meters—perhaps two or three hundred—and there they are a success; we get a fair revenue from them, but in the country they are a failure. Then with regard to a fixed charge per light, about which Mr. Dykes gave us some very interesting information, I know of two towns in which between a hundred

Mr. Highfield.

and two hundred consumers are charged so much a lamp. The result of that is that they pay 1d. per unit, and yet they are not satisfied. I think that the fixed charge—at least so far as my quite small experience goes—is a failure. I fancy the reason is that one consumer is rather careful; he sees his neighbour next door burning his light all the time, and he does not think it fair because in some way or other he thinks he is paying for the light of the man next door, who is not so careful as he is. I can think of no other explanation. Another rather interesting point is that with regard to these several thousand slot meter consumers (and, as I told you, the slot meters were a failure because the consumers would not use the energy)—a large number have been converted to what we call the weekly contract system. Instead of paying, as in Mr. Seabrook's case, so much a year, they pay a small sum per week—6d. or 1s.—and for that sum they are entitled to a limited number of units, usually enough for their own purpose. If they use any more they pay 1d. or 1½d. a unit. That system has been quite successful. A good many hundred of these slot meter consumers, who would not burn any electric light before, are now quite good consumers. In connection with the charge for electric cooking, I consider this a most important matter, because I do not think there is any general experience of what the cooking load will mean. There is very little cooking done at the present day by electricity, and very few people appreciate how good it is. A great deal of the advertising of electric cooking apparatus is done on the basis that electric cooking is very much better in quality than any other form of cooking. We are reminded of the picture of two legs of mutton, one being half the size of the other, the smaller one having been cooked in the gas oven and the larger one in the electrical oven. The claim is for quality. I think in selling anything it is a mistake to say that what we are selling is the best quality and at the same time that it is the cheapest. I do not believe we shall get anybody in the world to believe that. I believe it is a great mistake at the present juncture to reduce the price for energy for cooking apparatus to too low a figure, because we do not really know what the cost of supplying the cooking apparatus is going to be. I do not think that at the present day it will affect the sale of electrical cooking apparatus whether we make the price ½d. or 1½d. per unit. In conclusion, I would suggest that the electrical press might publish a list of tariffs; and further, I suggest that every engineer or manager who is considering the adoption of a new tariff before taking the trouble to invent a new tariff should turn up this list and see if it is not already invented, and as far as possible make the new tariff conform with the tariffs in his immediate neighbourhood. The effect of indirect competition in electric supply is a most dangerous thing. I charge 3d., we will say, per unit to a particular consumer who wants a motor or other apparatus, and this particular consumer has a friend over the border in the neighbouring parish who pays only 1d. My man has no complaint to make of my 3d. until he meets the other man who is paying 1d. It is very dangerous to adopt such a plan; it takes away

a very large sum of money out of the electrical business, and everybody knows that we want all the money we can possibly get. Mr. Highfield.

Mr. L. E. BUCKELL: I do not think any of us can possibly overrate the importance not only of the rate per unit at which we sell, but the form of the tariff, and in the paper we get the importance of the form of the tariff very well brought out. The form of the tariff is, I think, really of more importance than the actual amount per unit. As Mr. Highfield has said, the price per unit which people pay means very little to them indeed. What does mean a great deal to them is what total amount per annum they think they are going to pay. By means of the Norwich system, the telephone system, the metropolitan system, and any of the other fixed charge systems that have been mentioned, we are nearer to telling the consumer actually what he is going to pay in the course of a year. Therefore this paper turns all our thoughts in the right direction. In setting out the points which need be considered in making a tariff the author has overlooked one or two minor points. One rather important thing is the question of what the object of the particular tariff is. In starting a new undertaking in a new district probably the rate per unit as well as the form of tariff should be different from the form of tariff that is needed to fill up the mains in the case of a system that has been running for very many years. There is a certain class of people that always come on in any electric light undertaking—the leading shops, the hotels, etc.—and almost any tariff will secure those people. Then after a certain time we have to get a much smaller class of consumer, and those people, the author thinks, can be obtained by a carefully designed tariff. I think we have to consider in talking of tariffs the particular town or district to which the tariff is to be applied, and also the condition of the undertaking. This may explain to a certain extent why adjoining districts so often have different tariffs. It does not altogether explain it; but I think it will go some way towards it. With regard to the importance of providing a tariff which will offer the maximum inducement to people to bring their heating and cooking load on to the supply undertakings, I have been taking out some curves, which I have with me tonight, and which I shall be glad to hand round, showing in the case of a house where there was no coal or gas, only electricity for heating, cooking, and lighting, how the load varied during the day, and how the load varied in comparison with the load on the whole of the system. It is a little disappointing to find that in almost every case the lighting, heating, and cooking peaks coincided with the peak on the whole of the system. This only refers to one house, but it is quite a typical case. It is a house of the ordinary type with twelve rooms, and perhaps seven or eight people living in it; they have a late dinner, and do the average amount of entertaining. I think it would be very interesting if we could get more of this class of curve, because it is very important that we should know exactly what we are catering for before we offer too much for it. There is one form of tariff that the author has not referred to at all, and in some ways it is rather an attrac- Mr. Buckell.

Mr. Buckell. tive form. He mentions a flat rate per unit, and speaks of it as if he would have a flat rate applied to every consumer. A tariff could very easily be arranged by which consumers could be graded into three or four different classes and different rates per unit selected for each of those classes. I do not think myself it is a very good form of tariff, but it is worth considering for certain undertakings. The grading may either be effected by taking the demand for one year and working on the load factor, or by an arbitrary classification. In making that arbitrary classification it would not be any more arbitrary than the arbitrary assessment under the telephone system. In dealing with the flat rate kilowatt demand the author has touched on a very important and interesting point. I do not know how many supply engineers realise what an enormous amount of revenue the gas companies are getting from the smallest class of property—flats and small houses, and those houses apparently can only be obtained on a lamp per week basis. But so far the difficulty is to find any kind of lamp per week rate which is at the same time remunerative and sufficiently attractive to get the load. The author in his John Street premises is exceptionally fortunate; I am afraid we in the provinces have nothing like that we can get hold of. To start with, we do not get any caretakers, so that the property is not looked after in any way whatever. And further, the people who own this class of property in the big manufacturing towns are very unwilling to include the light with the rent, because in so doing they put up the apparent rent of their houses in competition with other people who have gas through slot meters, where the rent appears to be low, and, as a consequence, at any rate for the first two or three years, their property is not tenanted. I suppose as the advantages of electric lighting in such property gets to be more appreciated that difficulty may disappear, but in our case it has not disappeared yet. Rather an interesting case took place in my district as bearing on the fact that the form of the tariff and the simplicity of it, are at least as important as the actual price per unit. Some six or seven years ago it became apparent that our principal future increase of lighting load must come from residential premises, and, as I think was pretty generally the case, the maximum demand system we had in use was extremely unpopular among the occupants of such residential premises. We introduced a flat rate, and, as a result, for the next three years the average rate we received per unit was increased by about one-tenth of a penny, that is to say, not only had all the people who under the maximum demand were paying larger than the flat rate been induced to change on to the flat rate, but quite a number of people who were getting a lower average rate on the maximum demand changed on to it for the sake of simplicity. Another thing that has some bearing on the tariff to be adopted, and one that I think is often overlooked, is this. We hear a great deal of the importance of load factor in determining the price per unit at which we should sell, or the price per kilowatt at which we should sell, but I think we are apt to overlook the fact that load factor only takes stock

Mr. Buckell.

of the generating plant—of the plant which deals with the turning-out of the current; whereas the capital of the undertaking, or a great deal of it, is spent in mains, offices, parliamentary expenses, obsolete plant, etc., and we can increase the load on our mains without improving our load factor, although in doing so we are certainly improving the financial position of the undertaking. In large old undertakings we are a little apt to overrate the importance of load factor for lighting, especially now that other classes of load, power and traction, and that kind of thing, are automatically improving the load factor on the station. I think gross increased turnover is, at any rate, of some importance in relation to the load factor. We ourselves have decided to adopt the Norwich system, and we have adopted it after a lot of consideration. One of the principal reasons that we have done so is because it appears that under any sort of assessment system, just as under the old maximum demand system, we are offering a direct inducement to a consumer to keep his load low. With the Norwich system the direct inducement to the consumer is to increase his load; and as a matter of fact, although we have only had this system working now for about five months, the way in which the people have adopted it and increased their loads is extraordinary. I should think the average is at least 70 per cent. since they have been changed over on to this system, in some cases by additional lighting, in other cases by heating and by cooking. Of course, some of them have increased their load four or five times, but the average is at least 70 per cent. extra. We have put the system forward in rather a different way from that which is usually adopted. We have preferred to speak of the fixed charge as so much in the £ on the rating of the house. I think from the canvassing point of view that is rather an advantage. People are used to paying so much in the £ for the water rate, and for the poor rate, and the general purposes rate, and so on, and it is rather convenient to point out to a man that his electric lighting fixed charge will be about the same as his poor rate, or 70 per cent. of his poor rate, as the case may be. In our own case we charge half a crown in the £ on the rating of the house (that is 12½ per cent.). The actual amount comes out very near to the poor rate, so that we can instruct all our canvassers to tell people that they will pay about the same amount as for the poor rate and an addition of 1d. a unit. There is one difficulty which applies in a large area which will not apply so much in a small one, and that is that the rating of the different houses varies so much in different districts. In a district that is going down a certain size of house will be rated at a lower figure, but that is not the case in a district that is rising. This does not matter so much, because in the district that is going down the people are also likely to make the least use of electricity, and practically, the amount we receive remains pretty much the same in both the poorer districts and the better class districts. In dealing with the Detroit system the author quotes from some American papers which are very interesting, and he mentions on page 387 one quite important

Mr. Buckell. point; that is, if we are introducing a new system involving a considerable fixed charge there is always the risk that the economical consumer will not adopt it; that the people who are already getting big bills will take on the new system at once in order to get lower bills, but that the people who are paying lower bills will not change. I do not think there is anything in that point; we certainly have not found it so. We have found that so long as the tariff is simple and well understood people will not bother very much as to whether they are paying 10 per cent. more or 10 per cent. less than they did before. Of course, if the new system made a difference of 50 per cent. they would grumble.

Mr. Cowan. Mr. E. W. Cowan: The author has paid regard to the fact that the price of electrical energy is a two-sided question, and that it does not do to keep our eye only on one side. There is in the first place, supply, and in the second place, demand. On the supply side, with which we are all familiar, we pay regard to all that affects cost, including first cost, running cost, efficiency, load factor, and the diversity factor, of which load factor is, of course, a function; and on the demand side, which the author took particular notice of, we pay regard to everything that affects the quantity of electricity which we can sell at a given price; its consideration includes the spreading of the knowledge of the use of electricity among consumers and potential consumers; the study and investigation of market conditions and the adjustment of prices to suit those conditions in respect of each use of electricity; and, lastly, the establishment of a simple and, to adopt a word which the author has used a great deal in his paper, an expedient tariff. I do not use the word because I think it is a right word to use; I think it is an inadequate and misleading word to use in that connection. Unfortunately we cannot measure the forces that affect the factor of demand precisely, and I think that explains why that side of the question has been so much neglected.

The author has been engaged for some years in measuring the factor of demand, and he has been doing so in the only feasible and practical way, namely, by experimenting. He has reported success at Marylebone with the system which he has been led to adopt after the experience he has obtained. I do not doubt that success, but I should like to ask one question in connection with it. I was for some time a consumer at Marylebone as a tenant of a flat, and I found that, for 1909 (estimating the bill for the December quarter, which I have mislaid, as being the same as that for the March quarter), I should have made a saving of 39½ per cent. by adopting the telephone system; and I cannot help wondering whether there may not have been a substantial reduction of price wrapped up in the telephone system which led consumers to take refuge in it, on the ground of "any port in a storm," feeling that they could not be charged very much more (Marylebone is a locality of very high-priced electricity), and they might be charged less. Nevertheless, I think that the telephone system has some particularly good points in it. First and foremost it embodies the

principle of classification, upon which principle I want to say a few words to-night. For the benefit of those who may not quite understand what I mean by classification I may perhaps in the first instance give an illustration. A bridge was built over a river in Venezuela some years ago, and the toll charged for the use of that bridge was 5 cents. It was found that the white men used the bridge, but the black men did not; they continued to use the ford. The company thereupon reduced the toll to 1 cent., with the result that both black people and white people used the bridge. But the aggregate income obtained

Mr. Cowan.

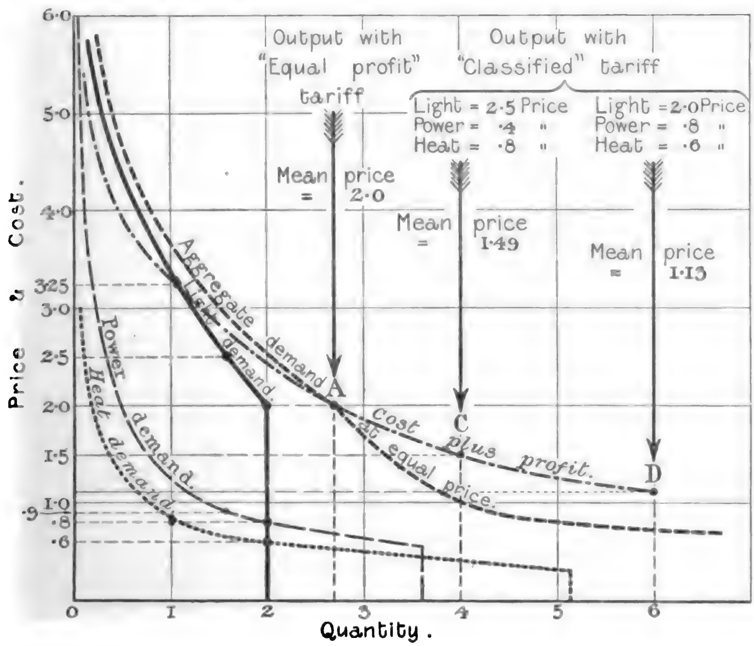


Fig. A.

was not sufficient to pay for the cost of working the bridge, maintenance, interest on capital cost, and so on, and the concern was a commercial failure. They then resorted to classification; that is to say, they did this: they charged everybody who wore shoes 5 cents., and those who went barefooted 1 cent. The result was that the bridge became a commercial success; the black people were pleased, and the white people were pleased; and other bridges were built across the same river and the same principle of charge was adopted. That is rather a grotesque instance of classification; but Fig. A, which I have not shown to the members of the Institution before, illustrates mathematically the essential economy of this principle of classification.

Mr. Cowan. In this diagram the abscissæ measure the quantity of electricity supplied, say, in millions of units, and the ordinates measure price and cost. Three demand curves are drawn, which represent the quantity of electricity that can be sold in any district at different prices. (For the sake of simplicity it is assumed that the load factor of each demand is the same.) A fourth curve, which is shown chain-dotted on the diagram, represents the aggregate of the three demands, and is obtained by summing their abcissæ. The last curve, which is shown dotted, represents what is sometimes called "the law of central station costs," that is, the relation between the cost per unit of production and the total output. Now, it will be clear that the price per unit at which the whole output of the undertaking represented by this diagram can be sold must lie on the cost curve if no losses or surplus profits are to be made. It is also clear that the price must lie on the demand curve if every customer who demands supply is to have it, and no customer is to be compelled to take supply who does not want it. Therefore, as the price must lie on both these curves, it must lie where they coincide, that is, in the diagram at their point of intersection, or at A. The price at this point is 2 (say 2d. if desired), and the quantity which can be sold at this price is 2¾ million units. This is the best possible result which can be obtained under the restricting influence of the maximum demand principle as a determinant of price, that is, the best possible result obtainable if price bears a definite relation to load factor. At this point all the consumers are treated equally, but not equitably—they are the victims of a grave injustice. Now apply to the same conditions the principle of classification, that is, the principle of adjustment of price to market conditions. I have shown the results of two classifications on the diagram, one at C and another at D. There are, of course, an infinite number of classifications possible. Let us examine the results of the classification at D. The light consumers are still charged 2d., but the power consumers are charged 0·8d. instead of 2d., and the heat consumers are charged 0·6d. instead of 2d. Thus the mean price is reduced from 2d. to 1·13d., a reduction of over 43 per cent. The percentage profit on working is the same as before, but it is earned upon a larger capital. The output is increased from 2¾ million units to 6 million units, or more than doubled. Now this result is obtained by deliberately violating the maximum demand principle as a determinant of price. Two-thirds of the whole output is sold at below "cost" price, the heat consumers at about half "cost" price. We are apparently making a profit by selling at a loss! We are, of course, really doing nothing so absurd, we are selling at a handsome profit. True cost of supplying separate consumers is not ascertainable in the electrical industry, though most of the systems in operation are based upon the supposition that such cost is ascertainable. Cost depends upon price quite as much as upon any other factor. (The lower the price the larger the demand, and the larger the demand, the lower the cost per unit of production.) The principle of classification can be

abused; but wisely administered, it benefits all concerned, consumers and producers. In some great industries its influence has been enormously beneficial. Why should not the electrical industry seek to exploit its possibilities to their fullest extent, taking all that it has to offer with both hands, instead of giving a grudging acknowledgment that, as it somehow benefits the balance sheet, it is "expedient" to recognise it? The telephone system, I admit, does classify, but it does so crudely by one rigid classification. The author agrees that it is expedient to do this, that is, to take a line which appears to him to be unsound from a theoretical standpoint. On page 383 he claims that the Hopkinson principle is the only scientifically correct basis of charge. I think it is not fair to the reputation of Dr. Hopkinson to claim that he advocated the maximum demand principle as a determinant of price. He meant that it should influence the charge, but at the time he wrote electricity was used only for one purpose, namely, lighting. Classification under such circumstances is not possible. It is those who have followed him who are responsible for the extreme view which I contend is unscientific. Then, worst of all, on page 384 the author quotes, apparently with approval, the following extract from the report of the Illinois Electric Convention: "It was the unanimous conclusion of all who have studied the subject of rate-making that rates, if equitable, must bear a definite relation to load factor." I submit that, either the unanimous view of the industry is wrong, or that my diagram is wrong—either one or the other—and I venture to challenge engineers who have studied this subject to show what is the mistake in my diagram, if there is one. I do not want to lay down the law in any dogmatic fashion, but there are times when it is "expedient" to call a spade a spade, and I think this is one of those occasions. At the same time, I think the author is travelling along the right road, and though he is doing so timidly and apologetically and inconsistently, I hope he may before long walk along it with a firmer step. I think there are signs of a change of view in connection with the system of pricing electricity, both in America and in England, but not in Germany. The opinion in favour of the maximum demand system as the determinant of price has predominated for very many years, but I hope that we may interpret the silence of the last two years as indicating that possibly that view is passing away. Mr. Cowan.

Mr. A. J. CRIDGE: I admire the author's boldness in mentioning "expediency" so straightforwardly as he does. There are plenty of people who have expediency in mind, but they do not often say so. I have had some experience of that myself. I remember at one time, in consideration of the load factor of public-houses, which close late and keep their lights burning considerably, that we deemed it expedient in Sheffield to offer a discount of 50 per cent. There was brought up before the committee a scheme by which this discount was offered to people who used electric light during ordinary licensed hours. The Conservative local organ said that it was no part of the duty of the Corporation to remedy an injustice which had been put on a deserving Mr. Cridge.

Mr. Cridge. section of the community by the machinations of a fanatical Government; while the Liberal organ accused us of pandering to the depravity of the masses. Expediency met with a nasty fate in that case. On page 379 Mr. Seabrook notes that some engineers are paying attention to the cultivation of a demand for auxiliary apparatus. I should like to offer a word to the wise there, namely, that if this paper were read at all the Local Sections of the Institution we might wake up not only some, but all the managers. I want also to criticise another point in the paper. The author has referred to all metal filament lamps as Osrams. There are others! On page 382 Mr. Seabrook mentions that a limiter costs nearly as much as a meter. That of course is not so unless he is talking of electrolytic meters. I want to mention, too, that it is a necessary thing to meter all the units that are sold. Everybody ought to meter his output and his sales with a view to watching the efficiency of the undertaking. Many engineers nowadays are trying to do away with the use of meters as far as possible, and I think that is an unwise policy. I do not say that because I happen at the moment to be selling meters, because even if a current limiter or a time meter is used, that falls also within my province. I should like to tell you of the experience of an engineer in one of the principal towns on the South coast where the undertaking is not municipal; I will not identify him any more closely. He once fixed up some working-class dwellings of a superior class with a contract system in which he measured the units *en bloc*. He did not like the system; he found it a failure, so he put in prepayment meters. His revenue went up, and the units used went down to one-fifth of what they were. If we adopt systems where meters are not used, it is an undoubted fact that we do get a great deal of waste. Many men who consider simply the money side of the matter say they do not mind about the waste of a few units, but in a case such as I have mentioned it reaches serious dimensions. On pages 385 and 387, the author criticises the Norwich system and says that it is inflexible. It is certainly inflexible, but I do not think that is any particular disadvantage. A water rate is inflexible, and a general district rate is inflexible, and although a large family naturally costs the community more in general service than a small family, yet if they live in the same sized house they pay the same rates. There is much to be said for the likeness between houses occupied by different people. If they are rated the same, the use of the light is very much the same. I went through a number of cases of that kind, and I found that was so. The Norwich system is based to a certain extent upon ability to pay, and I think that might also commend itself to the author with his views on expediency. It is quite legitimate to charge people to some extent on their ability to pay, and it would justify his charges being higher for a first-floor flat than they would be for a third- or fourth-floor flat. In several places in the paper we find reference to cases where people are not allowed to use any other illuminant. I should like to hear somebody's view as to the legality of that, because I was told it was restricting the liberty of the subject, and that we were

not allowed to make any such stipulation. Further than that, there are cases where we cannot absolutely throw out the gas. In some places it is necessary to keep gas burning for the sake of warming the atmosphere generally where electric heaters would not be useful; for instance, in the public-houses which I mentioned and licensed premises of the Bodega type, the wine casks must be kept at the proper temperature, otherwise the business is unsatisfactory. Whatever the telephone system may be based upon, I do not think it can be said to be based upon the load connected. In so far it enables the chief engineer to do what he likes with the method of charging, I think it is a good system. The chief engineer has to be a very good and capable man, and I do not say there are chief engineers at present who are not good and capable men, but the occasion may arise some day when there will be such men, so that we ought really to use a little more strictness than the author appears to be using in the determination of the maximum demand. Mr. Cridge.

Mr. W. E. BURNAND: The word "expediency" in the early part of the paper is rather an invitation to misconstrue the principle involved, this principle as I take it being that indirect profits, such as advertisement, should not be ignored, and that to insist on an equal rate of profit on all classes of business will lose business that would otherwise help to reduce costs. Most tariffs, in fact, become a compromise between what the suppliers must charge to cover costs, what they would like to charge, what the user thinks he ought to pay, and the manner in which he will most readily pay it. The result of comparison between tariffs boils down to this—that the best tariff is that which enables the cheapest units to be supplied for a given profit. A good tariff should thus have a constant tendency to decrease costs by increasing output, and to decrease the standing charges per unit supplied. The first item indicates the necessity for cheap units and absence of restrictions, and the second the desirability for some control over the peak. The tariff should also automatically bring in the correct revenue without alteration as the load factor alters. Missing as far as possible ground that has already been well covered, I think there are two points that are in some danger of being overlooked or under-estimated. The first is that efficiency in lighting is not going to stop with the tungsten lamp, and I think that a big increase in efficiency, probably by developments in vapour tube lighting, is nearer than is commonly realised. This, combined with increase of other uses, must result in alteration of present load factors, and probably the lighting load will take second place where it is now predominant. If other uses are not developed and lighting revenue is chiefly depended upon, this increased efficiency will hit the suppliers of electricity harder than the tungsten lamp did, and a simple rise of the price charged per unit will not get over the difficulty, as the customers will not pay double or treble, and other forms of lighting are not likely to stand still. The second point is with respect to peak load. I do not think it is sufficiently realised that peak load is just as profitable as load at any other time, provided it is Mr. Burnand.

Mr. Burnand.

well within the plant capacity. For instance, with a plant capacity, say, of 6,000 k.w., and a peak of 4,000, there is just as much profit on an additional 1,000 k.w. on the top of that peak as if it was right in the valley—it costs not a penny more in plant, staff, or coal; slightly less, in fact, on the latter two items. The only peak load that is actually expensive is when this exceeds the average peak, which leads to the generating and distributing plant being larger than would otherwise be needed. For this reason I think that both the maximum demand and a form of contract that has otherwise much to recommend it—off peak load—are to some extent faulty, in that nine times out of ten when they tend to reduce or restrict load this is no benefit to the suppliers, and only results in loss of revenue, and inconvenience to the consumer. The maximum demand that governs the plant capacity is not the individual maximum demand from month to month, but the total maximum demand at abnormal times during the year, and for this reason I think that a differential rate should apply the high rate indiscriminately to all consumers, and only during those few hours per year when the demand approaches the plant capacity, or perhaps on very large systems, the distributing capacity of each main section. The system I would propose would therefore have three items: First, a fixed charge corresponding to the actual cost of the various classes of service, for instance, the fixed costs for 10-k.w. demand for lifts—due to diversity factor—would not be as high as 10-k.w. demand for 50 hours per week service. Secondly, a low rate per unit for all current used. Thirdly, an additional higher rate for all current used at the specially high peak when the load approaches the plant capacity. This combination would, I think, exert a constant tendency to efficiency, whilst leaving the utmost liberty in the use of current at all times but the few hours per year when restriction is actually beneficial to the suppliers. This involves a two-rate meter, the high rate on which is controlled automatically, or by the suppliers, when the total maximum demand approaches the plant capacity, and I am sure it does not pass the wit of man in general, or the electrical man in particular, to devise the mechanism for this, at a low cost per consumer. Of the systems described in the paper, I think an attractive case is made out for the telephone system by its results, but I cannot help thinking that much of its success is due to the personality behind it. It is not every one, for instance, that would have the temerity to ask for three-fourths of the bill in advance, but Mr. Seabrook does more than this—he gets it—£25,000 for a start. I do not think it is quite sound to put all the standing charges on the lighting, as, with the increase of other uses, and the increase in lighting efficiency which we must expect, this is likely to overload and retard the development of lighting, and leave very little eventually for the standing charges to stand upon. At the same time, the business instinct of Mr. Seabrook is not likely to go far astray, and at 1d. per unit on the fair load factor that should result, I do not think the Marylebone Supply Department will go bankrupt.

Mr. C. G. BARKER: The contract demand system is, I think, much the best system that has, as yet, been advocated. The author says, on page 389, that "On this system the primary charge is based on the connected load." Is that right? I always understood it was based on the estimated maximum demand. Then he says: "The disadvantage which puts the contract demand system right out of court is the impossibility of using electricity for other purposes than lighting." This is not so at all. The point of the contract demand system is that it restricts one from using the heating, kettles, and irons, and so on, at the time of the peak load, which is just what the station engineer wants. One can use it in the daytime when one has not got one's lights up, and one can use any heating and cooking apparatus the maximum demand of which does not exceed the total lighting demand. In the same paragraph the author says: "Authorities on tariff making, both in this country and abroad, are agreed that energy for other uses than lighting can profitably be charged at the secondary charge only, and that no primary charge should be attached to it." Not being an authority on lighting, I beg leave to differ. It seems to me that if the cooking, heating, and so on, comes on at the time of the peak load and increases the maximum demand, that part of it which is in excess of the ordinary maximum demand should bear its proportion of the standing charges. Mr. Barker.

With regard to the telephone system, the author says on page 393: "Each consumer pays his share of standing and running charges separately." I do not think a consumer does pay his share of standing charges if he is using the heating and cooking apparatus, which has no standing charge, at the time of the peak load. He should pay more then. The author further says: "A large amount of other apparatus than lighting can be connected to the lighting circuits without the expense of separate circuits and meters." It seems to me if we are going to put on what he calls a large amount of cooking and heating apparatus, we shall require extra wiring, because the existing wires in a good many houses will not stand it; and also "The system has not the disadvantage which many differential systems based on the connected load have, namely, discouraging the free installation of lighting points, because convenience and decorative lamps are not counted." That neglects one most important point, namely, the question of candle-power. It does not prevent us putting in additional lights, but it prevents us from increasing the candle-power in our important rooms. That seems to me a great pity. We buy a 2½d. gas mantle and get 50 c.p. We buy an electric lamp and probably get 16 c.p., and get a very poor light in comparison with the gas mantle. People go out of the house which is lighted with gas into a house which is lighted with electric light, and they say the electric light is very clean, but you do not get a good light. If we can encourage people to increase the candle-power of the lamps they use, it is just as good as getting them to use the current for heating and cooking, and that is a business point that should be aimed at. With regard to the author's

Mr. Barker. analogy between 1d. units and 1d. telephone calls, I do not see much in that. It would be just as good to say that we would charge ½d. a unit, which is the same price as our morning paper. On page 394 Mr. Seabrook says: "It is found in St. Marylebone that a very small house or flat uses on the maximum demand system 80 per cent. of the lamps installed at any one time." In our case it comes out at 66 per cent.

The following curves were got out for the purpose of determining whether it paid best to go on the flat rate or on the maximum demand system. Fig. B shows price per unit for any number of units on flat rate of 4¾d. and maximum demand rates of 7d. and 2d. Our maximum demand is 315 watts, which corresponds with 45 7d. units in winter and 15 in summer. It is clear that if over 82 units are used in winter it is cheapest

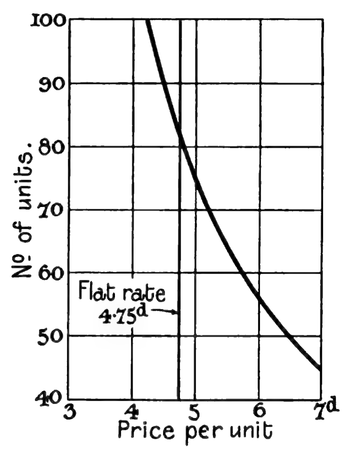


FIG. B.

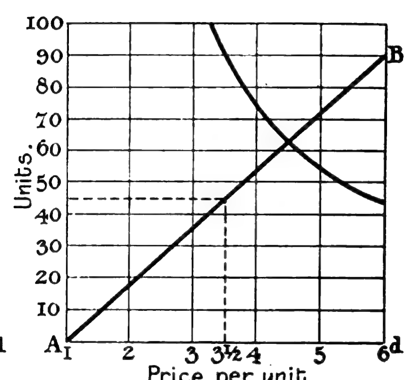


FIG. C.

to use the maximum demand system. Fig. C shows a preferable system of charging maximum demand at 6d. and 1d. all the year round instead of 7d. and 2d. with the ⅓rd scale in the summer. It also shows a quick method of arriving at the price per unit, and hence the amount of the bill. Thus if 90 units are taken, draw A B from O at 1d. to 90 at 6d.; the maximum demand is 45 units, and where horizontal through 45 units cuts the line, A B gives 3½d., the average price per unit. Fig. D shows in full lines the price per unit per quarter on each system, and the dotted lines the amounts of the bills for each quarter; A at 7d. and 2d., and B at 6d. and 1d. It will be seen that the 6d. and 1d. system causes a higher price in the summer when less units are taken, which is right, and also makes the bill for each quarter more nearly equal, which is an advantage. The total annual payment is the same in both cases, and the above system has the "business" advantage of the 1d. units for heating and cooking.

I think that the system with a contract demand indicator, which is simply what may be called a maximum demand system with an alarm signal fitted, is the ideal system. With regard to the cost of the demand indicators, that could easily be overcome. It would be easy to arrange a system of graduated fuses, by which as soon as a certain current was exceeded one fuse blew and the next one was automatically switched on, and the inspector could read the maximum demand by the number of fuses that had blown. Such a device is shown diagrammatically in Fig. E. These instruments could be made at a cost of about 4s. to Mr. Barker.

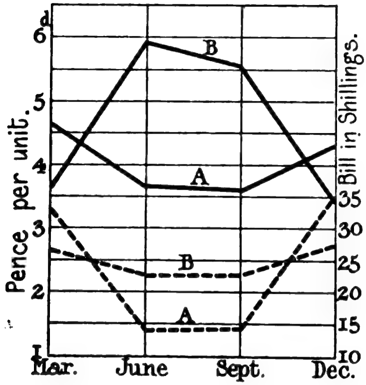


FIG. D.

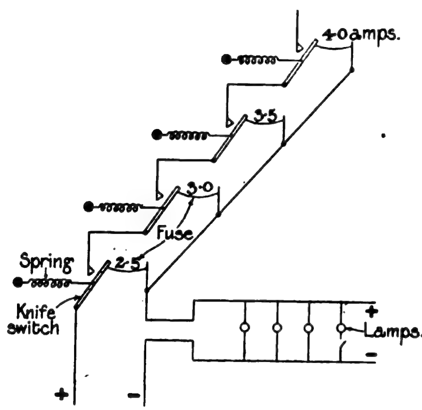


FIG. E.

take three or four different sizes of fuse. The "dimming" of the lights would tell the consumer he was exceeding his normal maximum demand.

Mr. JOHN F. DAVIE (*communicated*): Mr. Seabrook's paper is of very great interest to all supply company managers and others who are concerned in the sales of electricity, but his contention that no tariff is theoretically sound which does not differentiate between "running costs" and the "standing costs" is rather too dogmatic. "Expediency," however, allows the sale of electricity to consumers in the St. Marylebone district at any rate or on any system provided it pays, and, after all, that is what an electric supply business is out for. From personal experience there are many consumers whom I am acquainted with in St. Marylebone who remained upon the Metropolitan Company's flat rate of charge, and were very glad indeed they did so. Others who adopted the Wright system of maximum demand found that they were paying 8d. per unit for every unit they consumed. Now I am certain that the sales of electricity even for lighting cannot be pushed at this price. The telephone system of charge is not so ideal as the author would have us believe. One is continually being Mr. Davie.

Mr. Davie. faced with the wiring problem; premises fitted for lighting only with 1/18 or 3/22 circuits cannot be considered adequately "coppered." The lamps will in all probability show a distinct drop in volts if any apparatus consuming, say, 300 to 400 watts is put on circuit. The "other uses" units are therefore much restricted or confined to small flat-irons, little tea-kettles, and suchlike toys, which consume comparatively a small number of units, and will not help the supply companies' revenue to a very great degree, as would be the case if ovens or heating apparatus were installed. There is no doubt that a flat rate on a sliding scale between 6d. and 3d. per unit for lighting, and a low flat rate (say the now almost universal 1d. per unit) for other purposes, is more simple and easily understood. I will admit it leads to the duplication of meters, but after all this is more often than otherwise an advantage, as the consumer knows by his account how many "other uses" units he has taken, and pays for them as such. The author's own concluding statement of the simplicity of the "flat rate" system of charge is one which I am sure every supply manager will agree with, and one which is essential from the consumer's point of view. The telephone system of charging is clearly shown by the author to be more complicated than any other system, and is not conducive to getting business from the smaller consumers, or from the consumer who desires to be economical in his use of electricity. Metal filament lamps are slowly but surely ousting gas from basements, and even the "long-hour gas consumer" is beginning to realise the fact that electricity at a low flat rate is as cheap as his older methods of illumination and doubly as convenient. In London proper practically only small consumers are left for the sales department to convert for lighting. This brings us to the question of a "fixed price" rate, and it is a very interesting one for all who contemplate the extension of electricity to the smaller houses in their district. I believe it is the one practical solution for bringing over the small consumer from his gas to the supply company's mains, and I am sure that sooner or later great developments will be made in this system of charge, combined with initial installation charges and lamp renewals. Turning again to our main object, it is readily admitted there is an immense field open for cooking, heating, and domestic supply in the houses already connected, and I am sure all the supply company managers are quite alive to the fact. But most of them are also alive to the fact that it is very little use pushing upon their consumers apparatus which cannot be used with safety on their existing wiring. Therefore the "1d. rate" on properly wired circuits is getting nearer the eventual solution of the universal use of electricity for domestic purposes. The makeshift idea of overloading the consumers' wiring, courting breakdowns and "blown fuses," and the risk of possible extinction of the lighting cannot be considered an advertisement for electricity, even if upon the author's system the "other uses" units are obtained for 1d. each without the additional installation of power or domestic service circuits. The metal lamp has undoubtedly left many stations with spare plant, judging by the fact that we very seldom nowadays notice

a company or municipal body asking for tenders for more. The immediate future is in the hands of the commercial engineer, and the more simple and easier the tariff or charge is made for the consumer the sooner shall we require to enlarge our station capacity. Mr. Davie.

The following figures are given as a comparison between the telephone system and a flat rate of charge in a suburban residence, where the pressure is 240 volts :—

Total number of points wired	17
Total watts connected	526
Deduct inactive lights (bathroom and lavatory)	64
	462 watts

70 per cent. of 462 = 320 assessable watts.

Telephone System.	£	s.	d.	*Flat Rate.*	£	s.	*d.*
Annual charge	4	18	0	172 units at 5¼d. ...	4	1	10
Meter rent	0	10	0	Meter rent	0	10	0
Annual consumption—							
172 units at 1d. ...	0	14	4				
	6	2	4		4	11	10

Extra cost on telephone system, £1 10s. 10d. This, if desired, could be expended in 250 units at 1d. and 10s. for meter rent if house had been wired for other purposes.

If we take it that we wish to use other apparatus upon the same circuit we should then have the following comparison :—

Telephone System.	£	s.	d.	*Flat Rate.*	£	s.	d.
Annual charge	4	18	0	172 units at 5¼d. ...	4	1	10
172 units at 1d.	0	14	4	250 units at 1d.	1	0	10
250 units at 1d.	1	0	10	Meter rent, two, at 10s.	1	0	0
Meter rent	0	10	0				
	7	3	2		6	2	8

So that we still save £1, which represents 5 per cent. interest on a sum of £20, and surely we could get a very nice and efficient domestic electric installation, including apparatus, for this figure. Practically all the telephone system means is we can put on a flat iron or a kettle or a toaster, or some such small apparatus, with a current consumption not exceeding the capacity of the circuit to which it is connected. It will thus be readily seen that from the consumer's point of view the fixed charge or annual assessment makes them pay in the beginning at

Mr. Davie. a heavy rate, and would not be any benefit to the economical user of electricity. But it is of very great benefit to the supply authority, as it provides capital to carry out the company's business by insisting on payment in advance. In conclusion, I am more than ever convinced that the way to obtain additional business is to institute a low flat rate for both lighting and power, and put forward a "fixed charge per week per lamp" system for small consumers.

Mr. Bowden. Mr. J. HORACE BOWDEN (*communicated*): I agree with the author in the first paragraph, after setting out the basis of costs upon which charges for supply should be made, but in no other respect. In my opinion it should be regarded as a law in electricity supply that each consumer should pay a fixed charge per annum equivalent to the cost entailed by the undertaking, as far as can be ascertained, in order to supply each individual. After arriving at this charge or assessment, it appears to be quite a simple matter to fix a remunerative price (which should not deviate in any way excepting in the case of very large consumers) for the actual supply of energy. I, however, do not agree with the basis as set out by the author, and am greatly disappointed that he should have seen fit to make the bald statement that standing and running costs should be separately treated, and not refer in the body of the paper to the method of applying these costs in fixing tariffs. The whole essence of the paper is contained in the opening remarks, which is immediately vitiated in the second paragraph by his reference to "expediency." Charges must either be equitable or inequitable, and to consider "expediency" in making an inequitable charge is to admit that the governing factors are unsound. The author has omitted from the cost basis the all-important "service cost." Every consumer connected to the mains entails an individual charge upon the undertaking: in some cases it is the cost of connecting only, including meter, etc. In advanced undertakings it may include the wiring installation, and, when quite up-to-date, it may also include cooking appliances; but whatever direct cost an undertaking may be put to in supplying the individual, that cost should form the first item of the fixed annual charge. How the charge should be applied is, of course, a matter of opinion, but I may say that I consider 12½ per cent. upon the prime cost of the work to be sufficient to cover all expenses on a basis of 10 years life, and 4 per cent. interest equated over life. Repairs and renewals to be kept up out of the revenue from the depreciation allowance of 10 per cent. Standing costs, so vaguely alluded to by the author, cannot be so readily allocated to the individual; but, in my opinion, there can be only one method of dealing with the same. The author does not tell us exactly what are standing costs, and entirely omits to mention in the paper the method of application to tariffs. I wish to be emphatic in the statement that standing costs are those charges upon an undertaking which may be fixed within a certain degree of accuracy at the commencement of each financial year.

Upon consideration, it will be found that instead of a small proportion of repairs, wages, coal, etc., the bulk of the two former items will

Mr. Bowden.

be included, as any engineer can very well estimate the amount of the wages of the permanent men employed in the generating and maintenance departments for twelve months in advance. Casual labour, overtime, and materials cannot be estimated, and are therefore chargeable to "running costs." Probably the most difficult item to allocate to standing costs is the proper proportion of coal. I have had, during the past two years, opportunities of ascertaining within a fair degree of accuracy, the amount of coal required for readiness to supply. Poplar was in the fortunate position of being able to supply Stepney, while the latter undertaking carried out extensive alterations by the removal of plant from Osborne Street to Blythe's Wharf. A fairly constant load of 500 k.w. was required continuously in the summer months of 1909 and 1910. By deduction, I found that with coal of about 10,500 B.Th.U. value, approximately 1,000 lbs. of coal per hour was required for standby purposes, etc. This is a much more accurate figure than arrived at by deducting the summer units from winter units, and estimating on the excess coal, as the winter cost of coal includes peak load losses, which must be considered as running cost. It may be interesting to note here that the day load with its variable demands for power, and loss during dinner hour, is the most expensive of the three daily shifts, the evening load being second, and the night load third as regards running coal costs.

Running costs comprise entirely those costs which cannot be estimated within any degree of accuracy at the commencement of each financial year. Cost accounts can be so arranged as to show the exact amount of expenditure under these divisional heads, but it is one thing to arrive at these costs, and another to apply the same in fixing tariffs. The author does not make any attempt to do this, and therefore his paper is very much depreciated in value. We are presented with a treatise on seven different systems of charging, the last, but not least, of which is the "telephone" system. It is the telephone system in name only, inasmuch as the fixed charge is for 70 per cent. of the lighting service, everything else being thrown in free, and I have always found that the telephone company did not give much away. When analysed, however, the telephone system is really the ordinary maximum demand system in another guise. The St. Marylebone charge is 8d. and 1d., therefore £14 = 365 × 7d. × hours = 8d. for the first 1·315 hours per day and 1d. per unit afterwards. I am under the impression that the maximum demand system at St. Marylebone is 8d. for the first $1\frac{1}{3}$ hours and 1d. afterwards; if I am correct in my surmise, then the telephone consumer has only the privilege of paying in advance, and, from what the author informs us, the people in St. Marylebone have been induced to part with £25,000 in prepaid annual sums, which says little for the business acumen of the people of St. Marylebone, or speaks volumes for the astuteness of the St. Marylebone electricity department. It would be interesting to know what revenue is derived from the usurious rate of 10 per cent. increase for quarterly payments. I am not surprised to find that the author

Mr. Bowden.

avoided the complex question of applying the diversity factor to the standing costs of his undertaking, excepting in the instance of assessing lighting consumers at 70 per cent. of the watts connected, but am afraid, if we were to be initiated into the "expediency" factor, we would find concessions made to individuals which are governed by diversity in other boroughs. "Lower prices are charged for energy for arc lamps outside shops than for inside lamps. This is on account of their advertising effect, and also because of the nature of gas competition." That may be the author's opinion, but I can assure him that in industrial centres it is for no reason of this kind. A close study of the problem shows that where the peak occurs between 4 and 5 p.m., although business premises are lighted inside, a large number of outside lamps are not in use; therefore, for this class of lighting, whether arc or incandescent, it is quite equitable to apply a diversity factor of 2, and charge half the fixed charge as applied to inside lighting.

Again, in regard to domestic supply compared with business supply (I take it that although the paper is entitled "Residence Tariffs," the author is dealing with business lighting also, from his reference to outside arc lighting, and £25,000 in advance), the diversity cannot be less than 2, probably nearer 3 in areas, therefore if it is equitable to charge, say, £8 per kilowatt for shop lighting, the domestic rate should certainly not be more than £4 per kilowatt; however, this is a matter dependent upon locality and experience. Further, there is the internal diversity factor to consider. There are a number of domestic lights which can be designated as regular lighting, and others as occasional lighting; the author prefers to ignore the latter, but as they bear some relationship to the demand upon the undertaking, a charge in all equity must be made, and in my opinion an internal diversity factor of 4 meets the case, or a net diversity of 8 on the standing cost of supply equal to £1 per kilowatt for occasional lighting. The business policy advocated by the author is to charge on lighting the whole of the standing costs of the undertaking. It would be interesting to know what the financial result of last year's working would have been if the telephone system had been applied throughout. The capital charges alone amounted to £13,789, which divided by £14 equals a demand of 8,128 k.w., allowing a diversity factor of 1·5, this would make the consumers demand 5,420 k.w. The actual maximum demand was 8,333 k.w., and allowing 75 per cent. efficiency of distribution, the actual consumers' demand was 6,250 k.w.; thus if 13½ per cent. only of the maximum was for "other uses," £14 per kilowatt would merely pay capital charges on the undertaking. But the most astounding proposition in the paper is that no fixed charge for cooking appliances is made. In a district like St. Marylebone, 1,000 cookers in circuit would easily add 1,500 or 2,000 k.w. to the maximum demand, which would add at least £6 per extra kilowatt to the standing costs of this exceptionally heavily burdened undertaking. Can it be expected to squeeze a further £9,000 to £12,000 per annum out of lighting consumers?

The author tells us that 1d. per unit will cover *all* costs for other

uses; probably that is so, otherwise his undertaking could not even now show a net surplus, but why trouble to divide running from standing costs if the result is not applied to the tariffs? This is an admission that 1d. per unit carries with it a large proportion of fixed cost, so that lighting, in addition to being saddled with the whole of the standing costs is also made to pay still further standing charges in the 1d. per unit rate. £14 plus 1d. has no direct connection with fixed and running costs. With the low coal figure of 0·27d. per unit sold, the running cost of production will be slightly under 0·3d., therefore the profit (which is net profit, all other charges being included in the fixed cost) should not be less than 0·7d. per unit sold, or on the output of last year £36,000; therefore, as only £12,000 was realised, £24,000 of fixed costs was recovered in the 1d. per unit charge. I put it to the author that he would arrive at better results in the future if he could reasonably assess his standing costs to "all uses" and charge ½d. per unit for energy. On this basis he would have made a net profit of £15,500 last year instead of £12,000, and would probably have increased his output much more than was actually the case. I congratulate the author upon his change of opinion in methods of charging since his translation from East to West. When next door neighbour to myself he was a rabid "flat rater," and the low rate charge by West Ham was the subject of much controversy with consumers on my side of the border. It is also curious that he should first have had the telephone system suggested to him by Mr. Arthur Wright, as it is really very old in principle although sometimes labelled differently. As a matter of fact, a similar system had been introduced into Poplar and commented upon in the electrical press some time before the author left West Ham. In conclusion, I may state that, in my opinion, the paper does not bring us one step nearer the solution of the important problem of establishing a definite system of charging for a universal supply of electrical energy, and I can only reiterate an opinion to which I have often given expression when commenting upon papers of this description, that it behoves the Institution to take the matter in hand as a body, and evolve a system that will, at all events, bear the hall-mark of its approval. I cannot foresee in the future, on the policy laid down by the author, any other result at St. Marylebone than a huge demand developed by the use of cooking appliances at unremunerative prices, but out of evil may come good, as when (probably in the near future) the West is linked up with the East, the diversity in time of maximum demand will enable a reciprocal supply to be adopted, and so avoid the heavy peak charges which would otherwise react against the development of cooking by electrical energy. Mr. Bowden.

Mr. ALEXANDER DOW (*communicated*): I limit my remarks to a comment on the comparisons made in the paper between the telephone system tariff, and the Detroit system. The telephone system, as described and used, should work excellently, and I have no doubt that it does. The comparatively low rate adopted for the secondary, or meter, charge is one advantage. The prepayment of Mr. Dow.

Mr. Dow. primary, or standing, charge is another. If I had started the Detroit residence tariff in 1908 instead of 1898, I certainly would have made the primary charge higher and the secondary charge lower. But my public would not stand for payment in advance. It does stand for monthly settlements, and pays very promptly; in fact it insists on monthly settlements. In 1898 I was trying to make each unit sold carry its own margin of profit. In 1908, and now in 1911, I would prefer to see each unit sold carry some profit, but I recognise that in some classes of service it is better to bunch the profit with the standing charge, letting the running charge represent only operating expenses. I think, nevertheless, that the Marylebone method is carried to an extreme in that d rection; it would have been quicker business to cut the primary charge a little and load some of the profit on the running charge. Possibly Mr. Seabrook does not figure on a profit, but he must have an interest and funding account, which comes into the same category. But as to basing a residence tariff upon connected load, I cannot agree with Mr. Seabrook, and I do not think he agrees with himself. Possibly his customers will not put large lamps into holders originally designed for small lamps. This is a constant experience with us. And while it is capable of detection by a demand indicator, or by inspection, and while it is admittedly a breach of contract, yet a demand indicator and the inspection are just exactly what we want to get away from, and we do not want to establish conditions whereby a breach of contract, either intentional or inadvertent, is made easy or probable. He does not reckon convenience lights as connected load. The query follows, What is a convenience light? The ultimate definition must be that any light not required for lighting the room according to some customary standard, is to be considered a convenience light. And it follows that the number of rooms, or the floor area of rooms, must be taken as the basis whereon to estimate the watts required for this ordinary or normal lighting—which is exactly what we have done for eleven years in Detroit. Toronto has recently substituted the floor-area basis for the "number of rooms" basis. The effect of the change is negligible, but floor area is more logical. Moreover, the other cities in the Ontario hydro-electric league had chosen the floor-area plan, and the Toronto management thought it best to go with the crowd. Mr. Seabrook is going to arrive, or has arrived, at the room or area basis, by way of a theoretical connected load adequate for lighting a given number of rooms or a given floor area.

The seven advantages of the telephone system recited by Mr. Seabrook on page 393 are all advantages except No. 5. That advantage, as stated, is offset by the objection that in a house wired throughout, as required by the St. Marylebone rule, the connected load, as figured for tariff purposes, ought to become very promptly the normal connected load of a residence of equal size. If the rooms are wired the lights ought to be installed, and they almost certainly will be; with the result that either the customer will honestly report the

installation and pay an increased primary charge, or he will forget to do so, and the inspection department will sooner or later discover the forgetfulness and make a fuss. Our eleven years' Detroit experience of human nature is that it is much easier to have the fuss to begin with and get the customer started properly. It may be stated that the Detroit primary charge is so many units at 14 cents. (equal to 7d.), less a discount of 10 per cent. for prompt payment of bills. This is considerably lower than the 8d. named in the paper. The number of residences connected is now over 32,000. The average annual bill is $19.90. And the average rate per unit for the last twelve months is a small fraction under 6 cents. The population served is now over 500,000. Mr. Dow.

Mr. A. H. SHAW (*communicated*): Although the telephone system is no doubt a good system for districts such as St. Marylebone, where there are a number of comparatively large consumers, I do not consider it suitable for many smaller districts, and it is certainly not a tariff that can be adopted universally. Different districts require different tariffs, and I am sure the author with his experience would not advocate its adoption in such a district as Barking nor even West Ham. In Ilford we have a large number of small consumers, and such a tariff would be out of the question. Referring to page 380, tariff (*b*), "Flat rate per kilowatt of maximum demand, or contract lamp rate," I consider this a very good rate for small property if a reasonable return can be obtained. I am afraid, however, it would be found that the figures given by the author would not be obtained in many other districts. In Ilford I find that in small houses, free wired, with from four to six lights, and current through slot meters at an inclusive charge of 4½d. per unit, the average return does not exceed 30s. per house per annum. I had some experience of a similar tariff many years since in the West Indies with satisfactory results, the chief trouble being the continual inspection necessary to prevent certain consumers replacing their lamps by those of a higher candle-power. The chief objections to its adoption here are the necessity of: (1) a fairly high price; (2) all wiring and fitting having to be carried out by the supply authority; (3) the locking or inspection of lamps. Mr. Shaw.

With reference to the telephone system, I do not consider it fair to a consumer that he is allowed no rebate in case of removal. In this case if one party leaves shortly after paying his primary charge and another who has no communication with the first takes the premises, is the latter charged another primary charge at the same rate as the former? Also would the former not be able to claim that he was being charged at a higher rate per unit than that allowed under the order? I consider the primary charge of £14 per kilowatt too high, as taking this as a maximum demand rate based on 100 hours per quarter the price per unit would work out at 8·4d. I think £10 per kilowatt would be a suitable charge for ordinary undertakings. A great deal has been said recently of the advisability of having a single tariff so as to avoid the necessity of separate wiring for heating,

Mr. Shaw. etc. I do not consider this is such a great point as has been made out. The majority of houses are only wired for lighting, and in these days of cut prices the smallest sizes of wires allowable are generally used. Only small apparatus, such as flat-irons, etc., should be connected to this wiring, and if radiators or cookers are adopted separate circuits are imperative. To tell consumers they may connect any apparatus to any lampholder or plug at 1d. per unit may easily prove a source of danger. I believe the best policy is to make optional rates to bring in all classes of consumers. I do not consider it advisable to make hard and fast lines between so-called "good" and "bad" consumers, nor to be too nervous as to whether a consumer is going to be a "bad" consumer. Get them all in, for a bad consumer to-day may be a good one to-morrow, or may be the means of obtaining a good one, and in any event he is one less probable consumer for the gas company. Although we have various tariffs in force in Ilford we find that the large majority of lighting consumers prefer the flat rate, and I think this rate will have to be retained in many districts, as it is the only one many people can understand, and it is from their point of view the only fair one.

Mr. Ashton. Mr. A. W. ASHTON (*communicated*): For blocks of small flats like the John Street dwellings mentioned in the paper, a large reduction in cost could be effected where alternating current is available by installing condensers, either on single points where a low candle-power is sufficient, or with a number of points in series on one condenser. For small kitchens, bedrooms, etc., a 10- or 13-watt lamp is ample, and the use of a condenser enables advantage to be taken of low-voltage lamps, which are more efficient, more robust, and lower in first cost than 200-volt lamps. The following advantages are obtained with the series condenser system for all residences where not more than, say, ten 16-c.p. lamps are used at once: (1) The maximum demand is fixed by the size of condenser installed, and cannot be exceeded to any extent unless the capacity of the condenser is increased. (2) The reduction in light which occurs when the maximum demand has been exceeded is only about 5 per cent. for the first extra lamp, but is much greater when further lights are switched on. (3) Whatever number of lights may be switched on the power taken can never exceed the maximum demand by more than about 25 per cent. (4) The total cost of the condenser barely exceeds the amount saved by the difference between the first cost of the low-voltage lamps and of 200-volt ones. As an example of the reduction in cost which can be effected, it can be shown that by using 5-watt lamps in the lavatories of the John Street dwellings the cost per annum for current could be reduced from £4 4s. to £1 1s. per dozen lamps. Moreover, the cost of renewals would not be greater than for carbon filaments, for although the initial cost of the low-voltage tungsten lamp is about twice as much as that of the carbon, the life of the former is also twice as great as that of the latter. Where power is likely to be used for other purposes besides lighting a meter can be installed registering the whole energy taken, and provided all the lighting is on the series

Mr. Ashton.

system (in more than one group if the number of lamps is large) a tariff can be adopted which has the advantages of both the telephone and the maximum demand systems. Such a tariff would be similar to the telephone system in having a primary charge determined by the maximum demand, but this instead of being more or less arbitrarily estimated would be the actual maximum demand corresponding to the condenser used. The rate of the primary charge would be fixed so as to cover "standby" charges, and would amount to about 7d. per unit for 400 hours per annum. The secondary charge might be at 1d. per unit and would cover running costs alone. Where applicable this method would have the following advantages over other methods of charging: (1) Though easily understood by consumers it could be made to cover the actual cost in each particular case; (2) the consumer would be encouraged to keep within his assumed maximum demand, although a greater margin would be allowed than when a "limiter" is used; (3) the consumer would be encouraged to increase the number of lights installed, but could not increase his maximum demand without the supply authorities' knowledge.

Mr. Seabrook.

Mr. A. H. Seabrook (*in reply*): Mr. Highfield complained, and I think quite reasonably, of the difference in tariffs between adjoining areas of supply. One cause of difficulty was pointed out by a subsequent speaker, who said that the conditions of the capital commitments of the undertakings define, to a certain extent, what the tariffs shall be. That is the case, for instance, in Marylebone. Everybody knows the peculiar position there, largely due to the exertions of Mr. Highfield's Company in the past. What we are all hoping and praying for is that in a few years' time we may get some co-ordination of London Electric Supply. Mr. Highfield also laid great stress on the importance of getting a good price. I am thoroughly with him in that. He and some other speakers, including Mr. Cridge, are rather labouring under a delusion with regard to the question of forcing a consumer to adopt a tariff. We do not force a consumer to adopt a certain tariff. We give him so many inducements that it is very difficult for him to refuse. For instance, we maintain alternative rates. There are three or four rates a man can have, and we keep those rates at their original level. We do not reduce *them*, but reduce on the system of charging which pays us best, and the effect of this is that, as time goes on, the older rates become unused altogether. I quite agree with Mr. Highfield that the business of supply undertakings does not depend entirely on the cheapness of the tariff by a very long way. It is the salesmanship in connection with the business-getting department which has much more to do with it. With regard to the question of cooking, Mr. Highfield does not think it is necessary to go to a low price per unit for cooking purposes. The quality of cooking by electricity is much better than the quality of cooking by other means. We all know the saving in meat which is effected when electricity is used. I was rather amused the other day to see that the gas people are getting out an oven which is going to do the same

Mr. Seabrook.

thing. They put the joint in a closed tin, a sort of a double tin, and put that in the middle of the oven, and the same effect is got as in paper bag cookery, or as an electric oven, but of course it uses more gas because the heat is transmitted through the walls of the tin. There is no doubt about it, however, that the gas people are following up the advantages of electrical cooking very closely, and they are already right on our heels. Mr. Buckell referred to the fact that an old area wanted a different tariff from a new one. I do not quite think that; I do not quite agree with him there. I think the same class of load is desired in both areas, whether it is a new one or an old one, and the tariff should be so designed as to encourage the class of load required. I was much interested in his remarks about the quantity of electricity used in the house to which he referred. All the peaks for the various uses of electricity in that house coincided; they practically all came on together, and also came on when the main station peak was on. We do not find that in our analysis of "other uses" consumers. We find that 60 or 70 per cent. of the watts installed is the total of their maximum demand. It goes down to 30, 40, and 50, and it is only in the smallest houses that the ratio of maximum demand to watts connected goes over 70 per cent. I was interested to hear that Mr. Buckell has adopted the Norwich system. I suppose that in the country they do not have quinquennial assessments, which we have to put up with in London. I was rather wondering what they do when the assessment goes up or down. Does the consumers' annual charge vary as the assessment varies, or do they keep the annual charge constant? It seems to me it would be rather difficult to induce a consumer to pay a bigger annual charge for his electricity supply simply because his assessment is raised.

Mr. Cowan mentioned a very extraordinary saving with the telephone system in the case of his own flat. I can assure him that is not the usual result. When we introduced the telephone system we did not intend to make any reduction; we wanted to increase our income. It has often been the case that when electric supply authorities have put in force a differential tariff they have intended to make a reduction, and that by itself meant that a great number of consumers would come over to it. I think the system of charging mentioned by Mr. Cowan in connection with the bridge in Venezuela was a most excellent one—that the man with boots should pay 5 cents, and the man without any boots should pay 1 cent. It is a most sound business proposition, and according to his own statement it has had the effect of improving the balance sheet of that bridge. I say those principles should be adopted in electricity supply tariffs, provided we are within the four corners of the Electric Lighting Acts. Mr. Cridge mentioned that all units should be metered. I quite agree with that. Even if we supply artisans' dwellings at a fixed price per week, it is much sounder to have a master meter to measure the supply at the service, otherwise no one knows what the consumption is, and no one knows what the price per unit is working out at. We find in our own John Street

Mr. Seabrook.

artisan dwellings that the price per unit is practically the same as we should have got had they paid on either the maximum demand or the telephone system. Then Mr. Cridge does not think that the telephone system is based on sufficiently rigid figures as regards the connected load. I think if he looks into the tables rather more closely he will see that the basis is quite strict; it is fixed and unalterable. Mr. Burnand mentioned that efficiency in lighting did not stop, and that it is going to improve. In other words, we shall get a candle-power with less watts than we do now. That is a point where the Norwich and Detroit systems score over any other, such as the telephone system, which depends on the connected load. All those who adopt the Norwich system will secure the same annual charge that they get now, even if we get tungsten lamps or some other lamps of half a watt per candle, which is a decided advantage. Mr. Barker quarrelled with the fact that we do not charge the "other uses" units with their proper proportion of fixed charges. Mr. Murray chiefly criticises the telephone system, and challenges the factor of expediency in tariffs, expressing the opinion that electricity supplied for other uses than lighting which may come on during peak load time should be charged with standing costs. I wonder if he applies this principle to his own area. I must assume that he does—as he must naturally practise what he preaches—and that, for instance, he charges standing costs against all his power installations, makes no special terms for outside arc lamps, charges all his public lighting at full rates, and so on, and does all those correct and proper things that we all should do but most of us do not, because if we did we should not get the business. To my mind it is no greater sin to supply an electric cooker at a low charge—which is a seven-day-a-week load, uses more units in summer time than in winter, and consequently has a high diversity factor—than it is to supply an electric motor in a factory at a low charge, which only runs 5½ days per week, and is used on peak, and has practically no diversity factor. I fail to see why expediency should be, by common practice, allowed in a factory (which I admit is correct) and not in a residence. In fact, many supply managers allow a great quantity of lighting units, at an exceedingly low load factor, to be used in a factory at power rates. This is expediency stretched to a far wider limit than I am alleged to have stretched it in my paper, but I do not admit that I have stretched it at all. It is common practice to do all these things in factories, and I do not see why factories should be specially favoured. I admit that it is technically wrong to do it at all, but that it is financially beneficial to the undertaking no one can deny, and it is rather late in the day to question the practice. Apart from this, I do not for a moment believe that Mr. Murray is actually such a correct person as he wishes us to believe, because if he were he could not make his undertaking pay. As regards the details of criticism, I will only deal with the really important points, the small ones are found to disappear in practice—for instance, Mr. Murray's difficulty as to the honesty of the consumer, details of installations, and invasion of premises—there is nothing in any

Mr. Seabrook.

of them. The difficulties he imagines as regards the forms also disappear into thin air in actually working the system. Mr. Murray was emphatic that the telephone system was unfair, because it charged the consumer on an arbitrary assessment. I do not understand how Mr. Murray could have read the paper and then made that remark. This is one point where the telephone system particularly scores, because a man can put just as much or just as little illumination in his house as he likes (provided he uses no other artificial illuminant than electricity), and he pays for exactly the wattage he wants, not as in the Detroit and Norwich systems, which charge him an arbitrary primary charge regardless of his actual installation of lamps. It is true that in these systems he can take it out of the company by using the most extravagant lamps he can get, and pay no more primary charge by doing so, but he is compelled any way to pay on the standard basis of assessment if he wants to adopt the tariff. Mr. Murray, quite rightly, does not want to let any little point slip by unnoticed, and attacks the name "telephone." The reason this differential tariff was called the "telephone" system was because most of our consumers actually are telephone subscribers, whatever the position may be in other parts of the country, and the name in actual practice is found to be exceedingly helpful, whatever Mr. Murray may think to the contrary, and surely it would be rather unusual for a man to adopt the unlimited rate for the telephone in his house. Mr. Murray refers to the Illinois Convention Committee on rates having advocated the differential rate system, and then he says that every one of us will agree with that; but that is no reason why we should adopt a tariff (implying the telephone system) which is not based on sound premises. Well, probably Mr. Murray is not aware that the differential principle adopted as a standard in the States is that described in my paper as the Room or Detroit system, and that system has all the expediency and load factor peculiarities which the telephone system also possesses, and which Mr. Murray would have us believe are defects. The sole essential difference is that in the telephone system the primary charge is based on the connected load, and in the Detroit system it is fixed at so much per room; in both systems "other uses" units are charged at the low secondary rate only, and no primary charge is attached to them. Mr. Murray said, in conclusion, that he believed it was perfectly possible to formulate a tariff which is at once excessively simple, fundamentally sound, and a good business getter. Now that is the most clever thing Mr. Murray said. The selection of the word "fundamentally" is subtle in the extreme, because if he had said "technically" or "theoretically" I could have gone for him, as no tariff is workable which is only technically or theoretically sound, but "fundamentally" may mean such a lot. This, of course, admits of expediency forming a part of the basis, and in choosing the word Mr. Murray has left himself a convenient loophole for escape. I do wish Mr. Murray would bring out his perfect tariff from its seclusive "bushel," as no man in these days has any right to keep a tariff to himself; frankly, I do not believe for a moment that such a tariff as he

Mr. Seabrook.

describes can be framed. I must say that Mr. Wilkinson's remarks fogged me not a little. First, he says that the only difference between the telephone system and his own is that I get fat prices and he gets thin ones; then he proceeds to pick the telephone system to pieces, and can find no good in it. Does he realise that he is severely criticising his own system as well as the telephone system? I really think Mr. Wilkinson has fogged himself, because he goes on to point out that in his system he uses a limiter, and yet condemns my assessment method. That seems to be contradictory, because I was careful to point out that a limiter was a fatal error, because with it it is impossible to get customers to use other apparatus than lighting, which is the main object of modern tariffs. Mr. Wilkinson has a good deal to say about the high annual charge on the telephone system. Of course it is high, and I shall be very much obliged if any one will point out how, taking into consideration our capital expenditure, it can be anything else but high. When I had charge of an undertaking which could afford to supply at very low rates, my critics told me I was all wrong. Now I happen to be in charge of an undertaking with very heavy standing costs, I am told that my charges are too high. Mr. Wilkinson then criticises my condemnation of limiters, and does not agree that they cost nearly as much as meters; he then points out that the loss in the shunt of the meter is 1s. 2d. a year. Well, as it happens, I do not use meters with shunts, and I have not one on the whole system. The question of the honesty of the consumer also troubles Mr. Wilkinson not a little. I can assure him if he had any experience of the working of the system he would find there is no trouble in this direction at all. A great deal too much is made of this problematical dishonesty. If he will refer to the telephone agreement form, he will find that consumers have to permit inspection at reasonable times, and, as a matter of fact, the very small amount of alteration in candle-power that is found does not warrant for one moment the general statement that one cannot rely upon the honesty of consumers. I do not accept the aspersion on the character of the average householder, that he cannot be relied upon unless he is tied up all round by prevention of dishonesty. I suppose all of us by departing ever such a little from the paths of rectitude in our various capacities could make a great deal more money than we do, with very little chance of detection, but I hope it is not going to be implied because we all have opportunities of dishonesty, that we are, as a body, dishonest. Just let us apply these high-flown ideas to ourselves. I have found a very great gain for many years past from showing a reasonable amount of confidence in consumers, and if I have been robbed in one or two instances, those cases do not support any contention that consumers cannot be relied upon, and I am surprised at any supply engineer giving expression to any such sentiment. Then Mr. Wilkinson is very fidgety about the "other uses" units coming on peak and requiring extensions of mains, services, and plant. I dealt with this fairly fully in connection with Mr. Murray's

Mr. Seabrook.

criticism, and all I would suggest to Mr. Wilkinson is that he really looked into the question, to find out if it is not as profitable to the undertaking to supply apparatus, such as cookers, at a low rate per unit as it is short-hour motors which come on the peak of the load. One point in connection with Mr. Wilkinson's remarks as to what would happen when the time comes when new plant and mains are required: he says that we shall be compelled to put on the extra £14 per kilowatt for "other uses," but he overlooks entirely the fact that out of our £200,000,000 capital, about £1,400,000 will never be increased by any increase in output. Our existing capital is out of all proportion to our future capital expenditure, in connection with new plant and mains. I thought this was so obvious, but as the point has been raised it requires an answer. Mr. Wilkinson had some rather drastic comments as to the use by small consumers of electric heating and cooking apparatus. Now in the John Street tenements during December quarter of 1911, 900 units were used for lighting and *245 for heating and cooking at 1½d. per unit.*

Mr. Arthur Wright has raised an important point, which is the first valuable criticism I have yet had to reply to, *i.e.*, that difficulty may arise with regard to the assessing officials in determining whether lamps are decorative or useful, and his following remarks imply that he has the ordinary canvassing type of person in mind; but the men we employ for this work are our district representatives, men who have a thorough commercial and engineering training and have very considerable responsibility, dealing with all correspondence in their districts, quoting for all sorts of installations for sale, hire, hire-purchase, maintenance, and so on. They earn from £200 to £250 per annum, and are not at all of the Singer sewing-machine type of person at about 30s. a week, who is too often considered to be quite satisfactory for looking after the sales of electricity of even large undertakings. Turning to the data form, there are separate columns for "convenience" lights; each data form is approved by the sales manager and general manager, and although I have purposely queried many data forms and examined the installations myself, I have never found that our representatives have erred on the wrong side. Decorative lamps are very rarely claimed, as they have to be most distinctly decorative before they are passed. Mr Wright raised another important point—the question of discount. To provide for discount the annual charge on the telephone system decreases between 1 k.w. and 400 k.w. from £14 per kilowatt downwards. There is no discount off the 1d. units, but only off the annual charge, according to quantity. When we are in a position to make a reduction in price, and we are likely to be in that position quite soon, a discount off the 1d. units for prompt payments is certainly a method of reducing the price well worth consideration. I quite agree with Mr. Wright that in the case of small dwellings a lump sum per lamp per week is the best, requiring no measuring instruments at all. At present I do not know of any better solution of the problem than this.

Mr. Seabrook.

Mr. C. A. Baker criticises the paper from the point of view of a consumer, but I do not think for a moment he represents the biggest lighting consumer in the world with the demand of 2¼ million units per annum. It is quite true, as Mr. Baker says, that he has been up against the charges for lighting in Marylebone, and if he had not made some agreements with the Metropolitan Company before the Council took over the undertaking, and which the Council have not deemed it wise to interfere with, he would be paying a very much bigger price than he does now, on which he may congratulate himself. The fact that the standing charges on the telephone system, to Mr. Baker's schools, come out at more than the total price he pays under his old agreements, indicates the very unremunerative load afforded by school lighting. Mr. Baker then commences to lose himself on questions of price, and brings out the hoary argument that if the average capital costs per unit are 2d., how on earth can any one be supplied at a profit at 1d.? Mr. Baker thinks that the lighting consumers should be relieved on some of the charges, and that these should be transferred to the charges for "other uses" units. These things are mainly governed by the market value, which is a theme greatly beloved by Mr. Cowan. At telephone system rates of charge for lighting we can compete with gas, therefore why should we lower the rate, admitting that the primary charge on the telephone system carries charges that perhaps should strictly be put on the "other uses" units; but if they were put on the "other uses" units the "other uses" business would not be obtained, because the prices would not compare with those of competitors. At the prices suggested for "other uses" units electricity for heating and cooking can compare with its competitors, therefore why raise the price of "other uses" units and prevent oneself getting that business which is without a shadow of doubt remunerative. Mr. Baker then deals with expediency. In connection with expediency, may I say that I claim to have the right to use expediency within the four corners of the Electric Lighting Acts? If I do not go outside these Acts I take it that no one can claim that I am misusing expediency. With regard to renewal of lamps, Mr. Baker does not agree with giving lamps for nothing; neither do I, especially metal filament lamps, and I have never done so. Then he criticises the 25-c.p. lamps as giving too much light for a single room. That must be for the consumer to judge. As compared with the gas lamp, they certainly do not tell us that there is too much light; any way, they can have a 16-c.p. lamp, as provided in the schedule, at a lower price if they wish. It is too ridiculous to compare the charge to a consumer using one lamp to the charge for street lighting using 400-k.w. for 4,000 hours a year. As a matter of fact, the current used for street lighting is calculated on the maximum demand rates and comes out at 1·47d. per unit sold. I have a perfect horror of red-tape, but I did not make a mistake in publishing the Marylebone Electric Supply Committee's Report before the report was received by that committee, and the report was not made public at all until after it had been agreed by the Council. Mr. Baker, as a

Mr. Seabrook.

consumer, refers to the flat rate and objects to differential rates, but then he is not a supply manager, and the paper is written from the supply manager's point of view. However, I quite agree with Mr. Baker as regards rules and regulations. We endeavour to keep them down to the minimum and employ "expediency" in interpreting them, which takes a lot of the sting out of the most drastic regulations.

Mr. Cooper thinks that the Hopkinson principle is making headway. I believe it is making very great headway, and in time will be considered the only correct basis of charging for electricity. I am sorry Mr. Cooper does not agree to put the high-price units on a differential system, in the form of an annual or quarterly charge. It seems to me so much simpler to do so. I think Mr. Cooper takes a reasonable view of our annual charge in advance, and I really think he ought to turn his attention to managing supply undertakings. He has most distinctly a far better grasp of the commercial requirements of an electrical undertaking than the majority of the speakers who criticised this paper. Mr. Cooper also thinks that it is right to have a certain amount of faith in human nature; it is good business, at any rate. We may avoid obtaining £10,000 by not having such faith, but, on the other hand, we may make £10,000 and get swindled out of £100. There is surely no difference of opinion which is the better of the two. With reference to Mr. Cooper's question as to the frequency of inspection, we make one official inspection annually for the renewal of the annual charge, and we make other inspections during the year where thought desirable. It can be taken as a general rule that we do not find anything wrong. If the consumer changes to metal lamps or reduces his watts we reduce the annual charge. This is only fair, as we increase the annual charge if the consumer increases his watts. The reason that there is a greater difference between living-rooms and bedrooms in the John Street dwellings is due to the fact that in this class of residence there is not the difference in the use of these rooms that there is in higher class residences.

I note that Mr. Dykes agrees that the flat rate should be as high as possible, in order to induce people to adopt the more satisfactory tariff. With regard to his remarks as to current limiters, we do actually adopt his system in cases where consumers will not agree to our 70 per cent. assessment and want something lower, but, of course, they are only able to use "other uses" apparatus up to the point at which the limiter is set. I do not want any misunderstanding as to our insistence on the complete wiring of a house for lighting before the telephone system is applied. The telephone system is intended to make it easy for consumers to use other apparatus than lighting. We have our standard rates which are applicable to any consumer under any conditions, but we give the special facilities of the telephone system if the consumer will agree to our special conditions, the most important of which is the exclusive use of electricity. I do not think it can be interpreted as holding a pistol at a consumer's head; it is simply a matter of arrangement. If the consumer's conditions are such that he cannot accept

Mr. Seabrook.

the telephone system with its advantages, then he is at liberty to adopt any other system in force. I quite agree with Mr. Dykes, that if we had nothing but lighting to deal with, the contract demand system would be exceedingly difficult to beat, but then we have this constant demand from consumers to use irons, toasters, kettles, grills, hair dryers, massage apparatus, curling-tong heaters, sealing-wax heaters, and many other pieces of apparatus, many or all of which can go on a lamp-holder, and nearly all of which are much cheaper to use than doing the same work by any other agency. The point is, that if the telephone system is unsuitable, what other system is suitable which will avoid double wiring? Mr. Dykes advocates the flat maximum demand rate for small consumers, and I am in perfect agreement with him; it is very interesting indeed to hear the results of his competition on this system with the South Metropolitan Gas Company, and I think he is much to be congratulated on his enterprise in finding a remunerative tariff which will suit this class of people. Mr. Dykes rather appeared to ridicule our agreement form and read out the one he uses for these small houses. I may say that we do not use any—no agreement, contract form, or anything else. I do not think it necessary.

Mr. Scott Moncrieff also deals considerably with the factor of expediency, which really seems to me, in view of this discussion, quite a new factor introduced into tariff making, whereas I thought it was almost as old as the Hopkinson system itself. Expediency has for years past been recognised in connection with charges for electric motors, why not for residences? The point with regard to the West Ham inquiry is not as Mr. Moncrieff states. He must know that the proposition he has put forward is entirely illegal. The point is, that if a generating station and mains system have been put down for a certain purpose—namely, lighting—and if that undertaking gets a different class of business, such as power, which was not thought of when the lighting system was put down, one is allowed to charge the additional capital expenditure in connection with that power supply against those power consumers, and one is not bound to take into consideration the original expenditure on lighting which has nothing to do with it. If Mr. Moncrieff knows anything about modern contracts for power supply, he will see by the very prices charged that the original costs of the undertakings have never been included in these charges for power. I apply them to Marylebone in the following way: I am unable to draw a line at 31st March, 1911, and say, Now all the lighting consumers I get after this date are additional business and can be charged at a lower price, because they cost less than the original consumers, but I can say that I will leave the price for lighting as it is to make sure of my standing charges (please bear in mind this compares with gas in cost), and then I can say to all consumers, I will supply you with electricity for all additional uses to lighting at a little over the additional cost of supplying them; the additional cost, of course, including the additional capital expenditure required in addition to the extra working expenses.

Mr. Seabrook.

Mr. Moncrieff criticises the payment in advance. Because I can get a high annual charge and in advance and because Mr. Moncrieff does not think it can be got in other districts, surely the only point that brings out, is the fact that our business-getting staff is of a pretty high order; and there is no doubt whatever as to the correctness of that.

In applying the telephone system of charge to the whole of our 20,000 k.w. of load, Mr. Moncrieff naturally finds a very big surplus, but he should bear in mind that our revenue from telephone consumers is small compared with our total revenue, and in the case of our big consumers we do not charge them anything approaching £10 a kilowatt and 1d. per unit. The annual charge decreases with the size of the installation, because the bigger the installation the greater the competition of private plant, and in fixing our tariff we have in mind all the way along the line the prices of other agents with which we have to compete. Mr. Moncrieff disagrees with my opinion that we shall never reach a universal flat rate, and he quotes towns where the total receipts are in the neighbourhood of 1d. per unit. Well, until recently I had the management of an undertaking where the total receipts averaged 1d. per unit, but the prices according to load factor and quantity ranged from one-third of a penny to 3d. for all supplies, and I know perfectly well that the people who were paying one-third of a penny would not pay ½d. much less a 1d., and if the people who were paying 3d. were charged a 1d. they would be supplied at a lot under cost. The result would be that the long-hour users who were paying a high price would discontinue the supply and generate their own, and the 3d. people being charged at 1d. would cause enormous increases in the lighting peaks. The load factor, instead of being a high one, would immediately turn into a low one, and the result would be that the undertaking could no longer supply at anything like an average price of 1d. It is all very well to make an estimation in such a case as this, but in actual fact I know it to be impossible. I would like to emphatically endorse Mr. Moncrieff's last remarks, and I only hope that when we get our *bigger* Institution (which we are certainly going to get in spite of present opposition) that one of the first things it will do will be to instruct its commercial section to form a permanent committee to investigate tariff-making, and to consider information from all countries and report developments upon this vitally important matter. It affects all sections of the electrical industry, from the heavy plant maker downwards. Mr. Long naturally advocates the Norwich system, and in those towns where it can be applied, I cannot imagine a more satisfactory tariff, but on the point of freedom to the consumer I cannot agree with Mr. Long, because in his system the consumer has to take and pay for an arbitrary standard of illumination. If he puts in an installation below the standard of illumination he pays no less, and if he puts in an installation exceeding the standard of illumination he pays no more: the latter people are the first who will be attracted to such a system. On the telephone system

Mr. Seabrook.

the consumer installs and pays for exactly the installation he wishes for Mr. Long also mentions the high rates on the telephone system, the reason for which has been explained. At the same time, I congratulate Mr. Long on being able to charge as low an annual charge as £4 per kilowatt. There is one point I discovered in discussing the matter with Mr. Long, that is that when he introduced his system, he intended it to be a reduction in price; naturally a great number of consumers immediately changed over to it. In Marylebone we wanted to get something simpler than the 8d. and 1d. system which would encourage the "other uses," but we were not in a position to make a reduction in price for lighting. Mr. Horsley was another speaker who supported the factor of expediency, and then proceeded to give an interesting description of the slot meter tariff in use at Harrow; but I am afraid the slot meter has the same objection with regard to the encouragement of other uses that the ordinary flat rate possesses. With regard to Mr. Ashton's communicated remarks, he raises an interesting point as to the use of condensers on alternating circuits for such premises as the John Street dwellings, and I have no doubt that alternating-current undertakings will look most carefully into the proposition. Mr. Davie, in his communication raises the difficulty of using other apparatus than lighting on lighting systems where the copper has been cut down to a minimum. Of course, obviously, in such cases the amount of other apparatus that can be put on is limited, but even in the small articles he mentions there is an enormous amount of revenue to be obtained. Although radiators can very rarely be put on a lamp circuit, it is very frequently found possible to take radiator circuits from the nearest distributing board of the lighting system. This is a big saving, as compared with running separate circuits from the bottom of the house. I am glad to see that Mr. Davie does not see much danger in a 1d. per unit for "other uses"; he may be considered one of the enlightened ones, but I do not think it is any particular advantage for consumers to know the number of other uses units used, which he says is one of the advantages of the double wiring system. Mr. Davie thinks that the telephone system of charging is the most complicated of any described, and is not conducive to getting business from the small consumers. Well, we find it is just the other way round. We get rather more small consumers, two- or three-room flats, and so on, adopting the telephone system, than we do the big houses. In the three-room flats, the "other uses" of electricity are so extremely useful to the consumer, as there is not room for a staff of servants, and we have had actual cases where the consumers have told us that using electricity for these purposes has actually saved domestic help. I do not agree that the small consumers are the only ones left for a sales department to convert to lighting; even in Harley Street, there are quite as many houses without a service as with one. I am glad to see that Mr. Davie agrees with the fixed price rate, and regards it as the practical solution for bringing over the small consumer. When we have time and are not engaged in more remunerative business, it is the intention in

Mr. Seabrook.

Marylebone to spend considerable sums out of profits on wiring premises on this fixed-price basis. It is a very much better way than investing money at 4 per cent. Mr. Davie imagines that overloading of wiring, breakdowns, and blown fuses will be the order of the day in systems like the telephone system, but if consumers are advised by competent people, and the work is carried out in a proper manner and under proper supervision, there is no more risk of blown fuses and extinctions, with other uses mixed up with the lighting system, than there is with the lighting system alone. Mr. Davie compares the telephone system with the flat rate in a suburban residence. He really should not compare Marylebone prices with those of other districts, because he must know of the special conditions applying in Marylebone which do not apply anywhere else in the country.

Mr. Dow, whose remarks I value very greatly, thinks it would have made quicker business to have reduced the primary charge slightly and increased the running charge. It will have been fairly obvious by now that the telephone system really consists of turning the 8d. units of the maximum demand system into an annual sum and charging 1d. per unit for all units used. There are considerable advantages, as set out in the paper, from adhering to the figure of 1d., and it becomes difficult to increase the demand for heating and cooking at a rate of more than 1d. At the same time, the 1d. carries a great deal more than the operating expenses and carries the cost of increased investment charges as well. Then Mr. Dow comments on the main difference between the telephone system and the Detroit (or Room) system. He still does not convince me that the latter is better, at any rate for British conditions. On the room basis the consumer's standing charge is based on an arbitrary standard of illumination; the telephone system being based on the connected load allows the consumer to install and pay for any standard of illumination he likes, and another great difficulty of the Detroit system, which is also that of the Norwich and floor area bases, is that consumers may install the cheapest and most wasteful of carbon filament lamps, thus increasing their maximum demand three or four times above that calculated for in arriving at the basis per room because the standing charge is not varied at all according to the connected load. With regard to the definition of convenience lights, our practice is almost the same as Mr. Dow's, by which he does not count rooms such as larders, lavatories, etc., the lighting of which is intermittent, so that there is no more difficulty with the telephone system than with the Detroit system. Then Mr. Dow says "that in a house wired throughout the connected load as figured for tariff purposes ought to become very promptly the normal connected load of a residence of equal size." This seems to indicate that there is a much bigger difference in the use of residences of equal size as between this country and the United States. People living in residences of the same size and character are very rarely found to require the same amount of illumination or to consume the same amount of units. Mr. Dow says if the rooms are wired the

Mr. Seabrook.

lights ought to be installed, and they almost certainly will be, but we find here it is not so. With regard to Mr. Bowden's remarks, I note it is his opinion that "it should be regarded as a law in electricity supply that each consumer should pay a fixed charge per annum, equivalent to the cost entailed by the undertaking in order to supply each individual." This is, of course, very commendable, but it is quite impossible to do it. All we can do is to get as near as expediency admits to this ideal. Even Mr. Bowden excepts large consumers. Why does he make this exception if he does not believe in the factor of expediency? My critics say I am wrong because I admit the factor of expediency; then one man gets up and virtually says that he may use expediency in a factory, but I may not use it in a house, and here we have Mr. Bowden claiming the right to use expediency with large consumers, at the same time condemning me for using it in residences. Mr. Bowden criticises me for stating that standing and running costs should be separately treated, and because I do not refer in the body of the paper to the method of applying these costs in fixing tariffs. Surely this is a matter which depends upon each particular undertaking; conditions differ in each locality, as I pointed out in the paper, and each manager must apportion his fixed and running charges according to his own conditions. Mr. Bowden says I have omitted the all-important service cost; as a matter of fact that is not at all important, and in the case of St. Marylebone the meter rent covers meter and service cost in the great majority of cases. I do not think it necessary to introduce a third factor, although I know it is frequently done in the United States. I do not agree with Mr. Bowden's definition of standing charges, and my description of standing charges in the first page of the paper is as close as can be given in a general way. Any closer allocation must be done separately by each undertaking. As regards the diversity, I thought it was obvious that the reason of the "other uses" units being put in at 1d. per unit was on account of their diversity. With reference to the diversity of arc lamps outside shops, I do not agree at all with Mr. Bowden's factor of 2. It is not the general experience, as any one can see for himself, because practically all arc lamps outside shops are turned on just before dusk. Mr. Bowden thinks that the proposition to supply cooking at 1d. per unit with no fixed charge is astounding. When Mr. Bowden gets more experience he will not think it at all marvellous. Mr. Bowden refers to my weakness for flat rates when at West Ham and complains that the low charge there troubled him somewhat. As regards the low charge, surely 3d. per unit cannot be considered low for the high load factor lighting in such an area, where people do not leave their houses for six months at a time and go to the South of France. A differential tariff is mainly to encourage "other uses" of electricity, and in those days "other uses" apparatus hardly existed in a reliable form, and besides, the class of resident was not that likely to make great use of the other applications of electricity than lighting. Mr. Bowden is very

Mr. Seabrook.

anxious to have it known that he has adopted a similar system to the telephone system for some years past. If the system is as bad as he tries to make out in his criticism, the obvious question is, Why is he so anxious to mention that he was a pioneer of this kind of tariff and thus deliberately share with me the opprobrium of putting in use an unsuitable and unsatisfactory tariff? It is rather amusing to me to note the melancholy prophecy of what is going to happen in St. Marylebone, due to the adoption of the telephone system, and encouraging a huge demand for cooking appliances at unremunerative prices. I believe Mr. Bowden was one of those who very severely criticised any engineer who offered electric power at sufficiently low rates to compete with other agencies. Mr. Bowden has been converted with the others in this direction, as I believe the power rates offered in Poplar now are fairly low. When he has obtained the same experience of electric cooking and the diversity of such load he may perhaps alter his opinion in this direction also. The point I must take exception to, is his remark *re* cooking units at unremunerative prices. The price named is not unremunerative; on the other hand, at 1d. per unit all round it is highly remunerative business, so much so that for the six summer months in St. Marylebone, we are supplying this class of load at ¾d. per unit.

In reply to Mr. Shaw, I find that a very great number of small consumers, 3- and 4-room flats and small residences, adopt the telephone system. I quite agree that different districts require different tariffs, but I do not agree at all that in Ilford, because of the large number of small consumers, such a tariff would be out of the question. I should think it is rather difficult to substantiate such a statement unless such proposals have actually been put to a number of residents. Mr. Shaw is afraid that the high figures given in the paper could not be obtained in other districts. I do not see that it is necessary to obtain such prices. Ilford should be able to charge quite easily £8 or £10 per kilowatt per annum and 1d. per unit, so that Mr. Shaw's first objection to the telephone system, namely, "a fairly high price," is no objection at all, because the price must be settled by the conditions in each district. I have no idea as to the reason for this statement. There is no necessity whatever for the wiring and fitting to be carried out by the supply authority. Locking and inspection of lamps: I have dealt with this in replies to other critics. Mr. Shaw does not consider it fair that no rebate is allowed to telephone consumers on removal. The telephone system is not forced upon people; it is never adopted by any consumers, unless it is to their advantage. There are two or three other rates available. Mr. Shaw does not think the telephone system of much advantage because it avoids the necessity of double wiring. I am afraid he is quite in the minority on this point, but of course he has an absolute right to his own opinion. There is no necessity to create a source of danger by putting electrical apparatus on to the lighting system if there is proper inspection of installations, which there should always be in every electric supply undertaking. Mr. Shaw thinks the

best policy is to make optional rates. I entirely agree with him there. I believe in one rate to be recommended, but two or three other rates which the consumers may adopt if they wish. Mr. Seabrook.

Now what is to be gathered from the discussion?

First, I think it may be taken that a differential rate is to be preferred to a flat rate.

Secondly, that little, if any, constructive criticism has been forthcoming.

Thirdly, if the telephone system is all wrong, no better one has been put forward, though hinted at, which is valueless.

The remarks on the Detroit and Norwich systems do not show their superiority.

The maximum demand system was not referred to at all.

I think by far the most important point is Mr. Moncrieff's suggestion as to an Institution Committee on tariffs. That may lead eventually to a standard method of building residence tariffs. It must be admitted that the present position is somewhat chaotic and most unsatisfactory.

Proceedings of the Five Hundred and Thirty-first Ordinary General Meeting of the Institution of Electrical Engineers, held on 18th January, 1912—Mr. W. DUDDELL, F.R.S., Vice-President, in the chair.

The minutes of the Ordinary General Meeting, held on 11th January, 1912, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members:—

Joseph William Beauchamp.
Charles A. Blascheck.
William Casson.
Ernest Coates.
P. R. Friedlaender.
Hugh John Holder.
John F. Lamb.
Arthur E. McKenzie.
William Marsh.
Herbert A. Skelton.
William Steuart.
Edmund B. Wedmore.
Alan Williams.
Henry H. Wright.

From the class of Associates to that of Associate Members:—

Brudenell P. Boyle.
Mostyn R. Gardner.
Herbert G. Jenkins.
Arthur G. Shearer.
Harold H. Williams.

From the class of Students to that of Associate Members:—

Lewis Barber.
George W. Blankley.
Herbert Yates Denham.
Gordon Franklin.
Arthur Johnson.
Jeffrey S. Messent.
Alex. J. J. S. Paterson.
John F. Shipley.
Frederick Smith.

Messrs. J. B. Morgan and S. Hann were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Associate Members.

James William Atkinson.
John Marriott Buer.
George Henry Congdon.
Henry Ernest Crocker.
Thomas Francis Dillon.
George Henry Fawcus.
Percy Sylvester Fox.
David Bowie Fulton.
Alfred Brawn Gilbert.
William Green.
Habibur Rahman Khan.
Ernest Soloman Lance.
Philipp Alfred Laubach.
Alfred John Leigh.
Alexander Jenner Lovell.
Michael J. McAsey.
Hugh Mathias Mathiesen.
William Mayall Milnes.
William Robert Murray.
James Vernon Payne.
Bernard Hartley Peter.
Alan Roberts.
Harvey Allan Smith.
Arthur Stockham.
Walter Alfred Stradling.
John Dean Taylor.
Sidney Mark G. Teal.
Guy Stafford Thorne.
William Parker Ward.
Charles Skaife Wolstenholme.
William Henry Woods.

The CHAIRMAN: I have to announce that Mr. R. K. Gray has presented to the Institution a gold medal, which was presented to the late Sir Samuel Canning by the American Chamber of Commerce in Liverpool on the completion of the 1865–6 Atlantic cables between Valentia Island and Heart's Content, Newfoundland, together with a bronze replica of the reverse of the medal. I am sure that the members will desire to give a most hearty vote of thanks to Mr. Gray for his gift.

The resolution of thanks was carried by acclamation.

The discussion on Mr. A. H. Seabrook's paper, "Residence Tariffs," was resumed (see page 428), and the meeting adjourned at 10.5 p.m.

A SUMMARY OF THE THEORY OF THE PRODUCTION OF ELECTRIC OSCILLATIONS.

By AAGE S. M. SÖRENSEN, Associate Member.

(*Paper received 4th November, 1911, and read before the* NEWCASTLE LOCAL SECTION, *27th November, 1911.*)

The production of electrical oscillations, and their application to radiotelegraphy is to any one interested in electrical science a very fascinating subject. On the other hand, the literature available is either of a semi-popular kind or it is of a more detailed and extensive nature than is wanted by any except those engaged in the profession. It is therefore the object of this paper to give a short abstract of the main principles of arc and spark oscillators, which, without going too far into detail, should yet present the subject with, it is hoped, a reasonable degree of continuity. This object leaves little or no scope for the expression of original views, the paper being restricted to an abridgment of the existing literature; but it is the author's belief that the subject is in itself of sufficient interest to justify the appearance of this paper.

The Single Circuit.—If a condenser of capacity C be discharged through a circuit with self-inductance L and resistance R, the relation between the charge Q and the time t will be—

$$L\frac{d^2Q}{dt^2}+R\frac{dQ}{dt}+\frac{Q}{C}=0 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

The integration gives—

$$Q=A_1 e^{pt}+A_2 e^{qt},$$

where p and q are the roots in the equation—

$$Lx^2+Rx+\frac{1}{C}=0.$$

If p and q are real (if $R \geqq 2\sqrt{L/C}$) the discharge is unidirectional: if p and q are imaginary the solution by trigonometrical functions gives—

$$Q=Q_0 e^{-\frac{Rt}{2L}}\left(\cos 2\pi\frac{t}{T}+\frac{R}{2L\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}}\sin 2\pi\frac{t}{T}\right) \quad . \; . \quad (2)$$

which shows that the discharge is oscillatory with the period—

$$T = \frac{2\pi}{\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Generally $R^2/4\,L^2$ is small compared with $1/L\,C$, and then—

$$T = 2\pi\sqrt{LC} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

which is the Thomson-Kirchhoff formula.

The equation (2) gives the relation between the charge and the time. It will be seen that the amplitudes of the oscillations decrease with the time, the ratio between the amplitudes of two consecutive periods being—

$$d = \frac{Q_0 \cdot e^{-\frac{R}{2L} \cdot nT}}{Q_0 \cdot e^{-\frac{R}{2L} \cdot (n+1)T}} = e^{\frac{RT}{2L}} = e^{\frac{R}{2NL}}, \quad . \quad . \quad . \quad . \quad (5)$$

that is to say, a constant quantity, and the natural logarithm of this ratio—

$$\delta = R/2\,N\,L \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

is called the logarithmic decrement. If the ratio were taken at consecutive half-periods the ratio of the amplitudes would still be constant, but negative, and the natural logarithm would consequently be imaginary, unless the sign be disregarded in the definition of the decrement. Some authors reckon the damping decrement on the basis of the half-period; but it will be seen below that it is possible to generate oscillations, in which two consecutive half-periods show a considerable difference, whilst all complete periods are exactly alike. In this case the use of half- and full-period decrements would be confusing. A train of such oscillations would in respect to the full periods be undamped, whilst the single oscillations by comparing half periods would show an, at times even considerable, amount of damping. The effect on the single oscillation is, in both cases, that the wave-form differs from the pure sine-shape, but it will be more consistent to distinguish between—

1. Damping, in relation to a wave-train, and
2. Distortion of the wave-form, in relation to the single oscillation.

The practical side of the question supports this distinction. The selectivity of a wave-train will, of course, depend on the damping of the train; the less the damping, the more can the resonance be utilised; and a train of continuous, uniform oscillations will naturally prove quite undamped in this respect, so long as the wave is not abnormally distorted.

Coupled Circuits.—If n circuits are coupled together the differential equation for circuit p would be—

$$L_p \cdot \frac{d^2 Q_p}{d t^2} + R_p \cdot \frac{d q_p}{d t} + \frac{Q_p}{C_p} + \Sigma M_{p, r} \cdot \frac{d^2 Q_r}{d t^2} + \Sigma \frac{Q_r}{C_{p, r}} = 0$$

$$(r = 1, 2, 3, \ldots, p - 1, p\ 1, \ldots, n).$$

Here $M_{p, r}$ is the mutual inductance, $1/C_{p, r}$ the mutual coefficient of potential of circuit p to circuit r; L_p, C_p, R_p, and Q_p are respectively inductance, capacity, resistance, and charge, in circuit p, where the index p can have all values between 1 and n, except that for the excited circuit a term is added due to the exciting voltage. The complete solution of the n simultaneous differential equations need not be discussed here, as it is given elsewhere by P. O. Pedersen.*

Commonly the case of two circuits only is of interest, and as a further simplification it will be assumed that their resistances are negligible, and that the coupling is that due to their mutual inductance only, for which $M_{1, 2} = M_{2, 1} = M$; further, the two circuits are tuned to the same periodicity, that is, $L_1 C_1 = L_2 C_2$, and the degree of coupling, defined as $k^2 = M^2/L_1 L_2$, is introduced. The equations are then :—

$$L_1 \cdot \frac{d^2 Q_1}{d t^2} + \frac{Q_1}{C_1} + M \cdot \frac{d^2 Q_2}{d t^2} = 0.$$

$$L_2 \cdot \frac{d^2 Q_2}{d t^2} + \frac{Q_2}{C_2} + M \cdot \frac{d^2 Q_1}{d t^2} = 0.$$

Differentiation and elimination of Q gives—

$$(L_1 L_2 - M^2) \cdot \frac{d^4 Q}{d t^4} + \frac{L_1 C_1 + L_2 C_2}{C_1 C_2} \cdot \frac{d^2 Q}{d t^2} + \frac{Q}{C_1 C_2} = 0.$$

Integration by $Q = e^{a t}$ decides a from—

$$(1 - K^2) \cdot a^4 + \frac{2}{L_1 C_1} \cdot a^2 + \frac{1}{L_1^2 C_1^2} = 0,$$

from which—

$$a = \frac{\pm \sqrt{-1}}{\sqrt{L_1 C_1 \cdot (1 \pm K)}}.$$

The period is then—

$$T = T_0 \sqrt{1 \pm K},$$

where—

$$T_0 = 2 \pi \sqrt{L_1 C_1} \quad \ldots \ldots \ldots \quad (8)$$

or the wave-length—

$$\left.\begin{matrix} \lambda_1 \\ \lambda_2 \end{matrix}\right\} = \lambda \sqrt{1 \pm K} \quad \ldots \ldots \ldots \quad (9)$$

thus showing the presence of the different waves.

* *Jahrbuch der Drahtlosen Telegraphie*, vol. 4, p. 449, 1911.

When the damping is taken into account the calculations get somewhat more complicated, the result being that the two waves have different decrements.

In applying the above formulæ it must be remembered that they have been deduced for the ideal circuit, in which all the inductance is in the coil and all the capacity in the condenser; this is, of course, not the case in a practical circuit. In the case of direct coupling it may also be necessary to take the respective resistances into account besides the mutual inductance and mutual coefficient of potential.

Another factor which will need further discussion is the damping. It was shown above that the damping was measured by the log. decrement, as given by equation (6); the amplitude curve would be an exponential curve. In a practical circuit there are, however, several other losses which have the effect of decreasing the amplitude, besides the loss due to the resistance dissipating energy as Joulean heat. The other causes are: Dielectric hysteresis, brush discharge, radiation, and (in circuits with a spark-gap) the spark. The combined effect does not actually result in a constant decrement (for all periods), but for practical purposes it is found more convenient to reckon with an average decrement which is assumed to be constant. The equivalent resistance is then the resistance corresponding to the average decrement by equation (6), and the decrement is generally found by measuring the equivalent resistance (Bjerknes method).

The amplitude curve, due to a spark in an otherwise undamped circuit (and with no "ohmic" resistance in the spark), would be a straight line, *i.e.*, not the ratio of, but the difference between, consecutive amplitudes would be constant—in other words, the spark resistance is a function of the current. With an arc the case is exactly the same, and it therefore follows that R in equation (1), when applied to an oscillator, should be itself a function of dQ/dt, and in this case the integration could not be completed as above.

For the discussion of the problem of the oscillation-generating circuit it then becomes of importance to know this relation, $R = f(i)$, or better, instead the function—

$$E = i \times f(i) = F(i),$$

the relation between the difference of potential at the electrodes and the current in the discharger, which relation is called the characteristic.

The Characteristic.—For an ordinary conductor possessing only ohmic resistance the characteristic is a straight line rising from the origin ($\tan \alpha = R$), as seen in Fig. 1.

The characteristic of a direct-current arc is a curve approximating to a hyperbola. The highest point is the breakdown voltage for the gap; from here it falls rapidly with a small increase in the current. This part of the characteristic is in all cases very steep, the starting potential being several thousand volts, whilst at about 2 amperes the potential is commonly of the order of only 50 volts; for medium

currents (between 2 and 10 amperes) the steepness depends on the nature of the electrodes and the gas, and for currents of the order of over 10 amperes the characteristic is practically a horizontal straight line. This curve is shown in its general appearance in Fig. 2, and is the static characteristic, of which all points correspond to steady conditions in the arc. In the case of an alternating arc or a direct-current

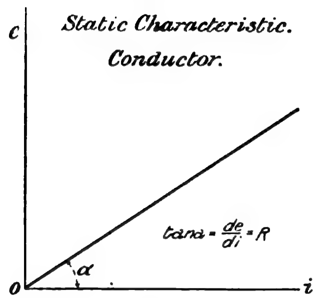


FIG. 1.

arc with superimposed alternations the characteristic is of quite a different shape, and is called the dynamic characteristic.

The Dynamic Characteristic.—It will readily be understood that when the current in the arc is first increased to a certain value and then decreased, the electrodes will not have time to get cooled or the gas in the gap to be de-ionised sufficiently for the conditions in the arc to be

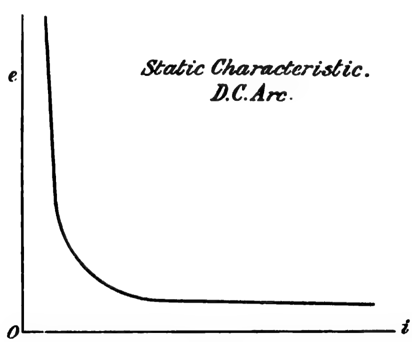


FIG. 2.

the same, when the current is passing through the same values during the decrease as they were during the increase, and consequently the characteristic will form some kind of a closed curve. This phenomenon bears so great a resemblance to the behaviour of magnetic hysteresis, that it is termed "arc-hysteresis." Fig. 3 gives the outline of such a dynamic characteristic.

The dynamic characteristics (and also the current and voltage curves) can be experimentally examined by the Braun tube, and a paper containing numerous such curves for the oscillatory arc has been published by Blondel,* whilst the theoretical treatment of the subject has been given by H. Barkhausen.† In the oscillatory arc the presence of both direct- and alternating-current accounts for three

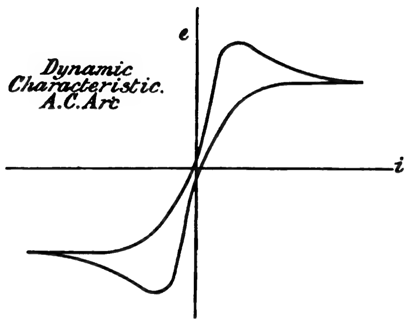


FIG. 3.

different cases which have to be considered, to each of which corresponds a different type of oscillation.

The First Type of Oscillations occur when the amplitude of the oscillations is smaller than the direct current. The dynamic characteristic is of the closed (elliptical) type, and the current curve nearly a pure sine-wave. With increasing frequency the hysteresis will increase

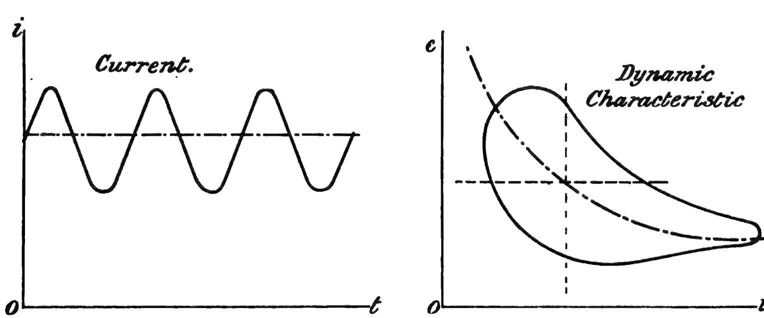


FIG. 4.—First Type Oscillations.

the phase-difference between potential and current, and therefore the output decreases. This case is represented by the Duddell singing arc, and as is known, this generator cannot produce any appreciable amount of energy for the frequencies used in radiotelegraphy. In order to obtain oscillations of this kind with an arc connected to an

* *L'Éclairage Électrique*, vol. 44, p. 41, 1905.
† *Das Problem der Schwingungserzeugung*, S. Hirzel, Leipzig, 1907.

oscillatory circuit, it can be shown that the corresponding part of the static characteristic of the said arc must be a falling one—that is to say, dE/di must be negative and less than the resistance of the direct-

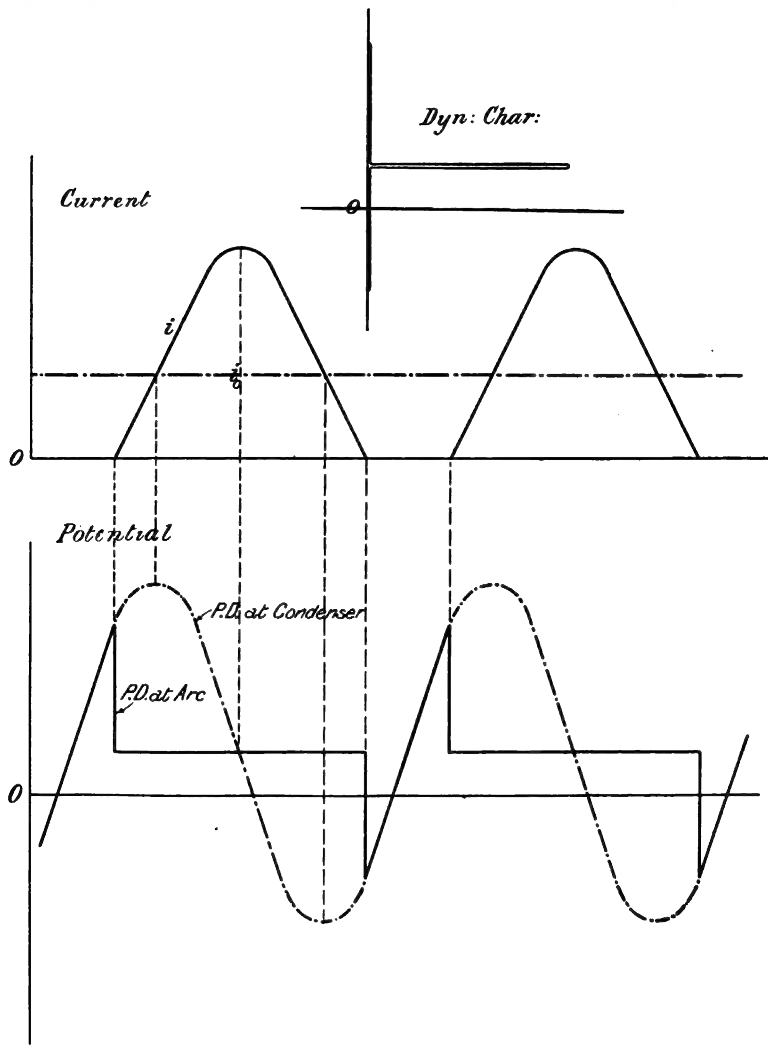


FIG. 5.—Second Type Oscillations.

current circuit. Fig. 4 represents the characteristic and the current curve.

The Second Type of Oscillations, which correspond to an oscillation

amplitude greater than the direct current, show a very different procedure. The current in the arc must be the sum of the direct current and the alternating current, and consequently at a certain moment becomes zero, *i.e.*, the arc is extinguished, and the potential difference at the electrodes falls from the value belonging to the

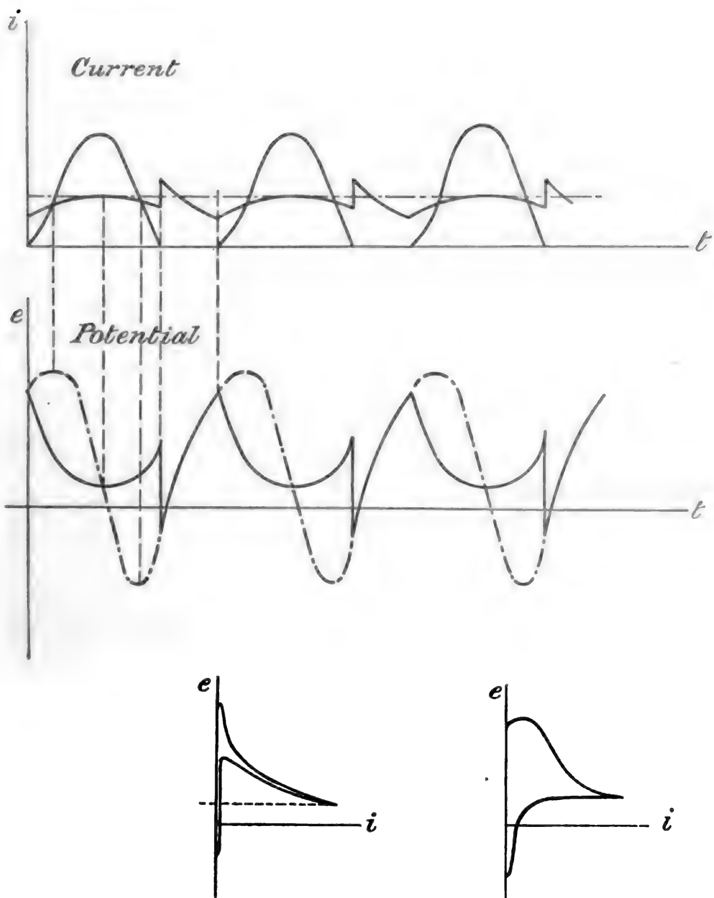


FIG. 6.—Second Type Oscillations.

burning arc to that of the condenser, which will then charge up under constant current (the direct current), and the potential will accordingly rise, along a straight line. At the moment this potential reaches a sufficiently high value to bridge the arc-gap, the arc is re-lighted, and the arc potential immediately falls to that corresponding to the arc when burning. Therefore the characteristic, and the current

and pressure curves must have the form shown in Fig. 5. When the arc is re-lighted the condenser discharges through the burning arc until this again causes the arc to be extinguished, and so on.

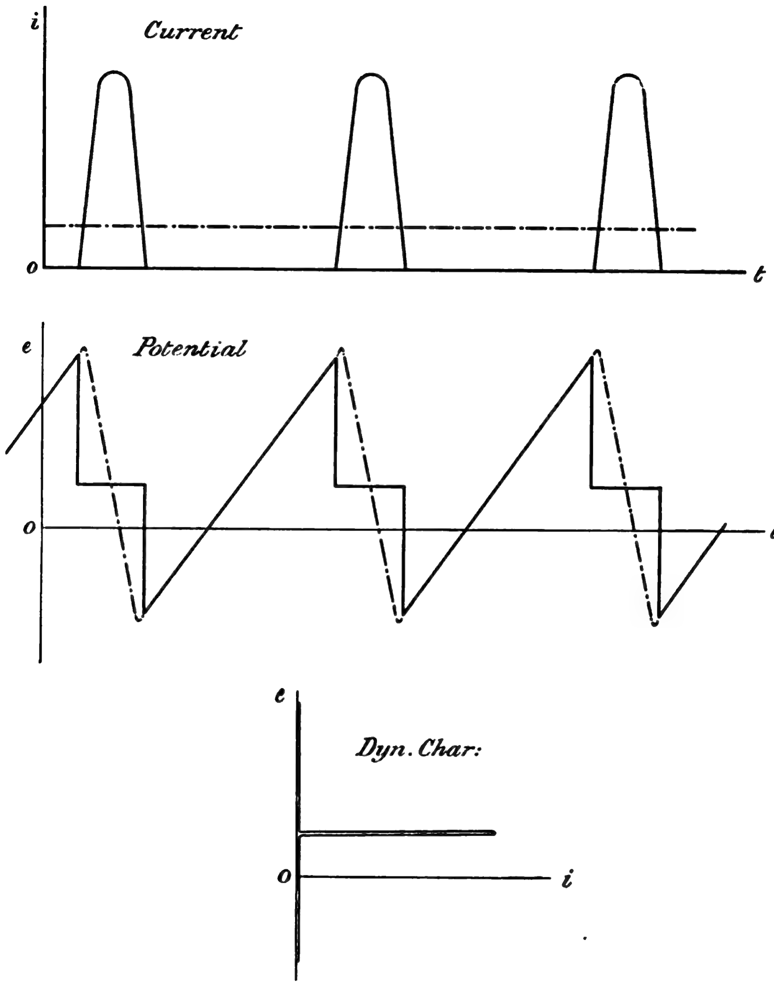


FIG. 7.—Second Type Oscillations.

Actually the fall in potential does not occur as abruptly as in Fig. 5, but the curves take the form shown in Fig. 6. An oscillation thus consists of two different intervals: in the first the current $i = i_0 + i_1$, is composed of the direct current i_0 and the oscillatory current i_1, the

period of which is $T_0 = 2\pi\sqrt{LC}$; but as this interval can only last between a half and a full swing, its duration must be such that $\pi\sqrt{LC} < T_1 < 2\pi\sqrt{LC}$. In the second interval the current is $0 = i_0 + i_1$ or $i_1 = -i_0$, charging the condenser C to the potential E, at which the arc re-lights; the duration therefore $T_2 = EC/i_0$, and the period of the complete oscillation is $T = T_1 + T_2$. It will be seen that the second interval is independent of the frequency of the condenser circuit; it may, in fact, reach values several times greater than the first interval, and the conditions depicted in Fig. 7 will obtain. In such a case the condenser circuit frequency is not very pronounced, whilst there is plenty of scope for harmonics. Such conditions prevail when the oscillation amplitude is great and the direct current small. When there is only a small difference between i_0 and i_1, the oscillations will be nearly sine-shaped, and will allow of resonance being utilised to a great extent. On the other hand, to obtain an appreciable amount of energy the value of E must be as great as possible, but this means a long second interval: the longer it is the cooler will the electrodes get, and the more the ionised gas is carried away from the arc-gap, the higher will be the potential required to break it down, and the greater the charge EC of the condenser.

Now, another way of obtaining this result would be to make i_0 large; but the gap must then be prevented from breaking down before the desired high potential is attained, which must now take place in only a small fraction of the complete period, and for this purpose the following means are adopted: Cooling of the electrodes; blowing away the ionised gas by a magnetic field; burning the arc in a gas with a great velocity of diffusion (hydrogen); and letting the electrodes revolve so that the arc re-lights on a cool place. An oscillation generator of this type is the Poulsen arc, with which powerful oscillations can be generated.

Third Type of Oscillations.—It has been shown that with the second type of oscillations the arc potential falls to that of the condenser at the instant the arc is extinguished, and the condenser then becomes re-charged; but if at this moment the condenser potential is sufficient to break down the gap, the arc will re-light in the opposite direction—in other words, the condenser discharge will be continued; and this may go on for several oscillations, until the arc finally dies out; then a second interval, as in the case of oscillations of the second type sets in, the condenser charges up, and the process is repeated. During the condenser discharge, however, no energy is supplied to the condenser, so that a short train of strongly damped oscillations is generated in each period. Fig. 8 shows current and potential curves; the oscillation frequency is that of the condenser circuit, but by regulation of the second interval, the train frequency can be adjusted to produce a musical note. A special case of the third type of oscillations with a very long second interval is nothing but the ordinary oscillatory spark discharge.

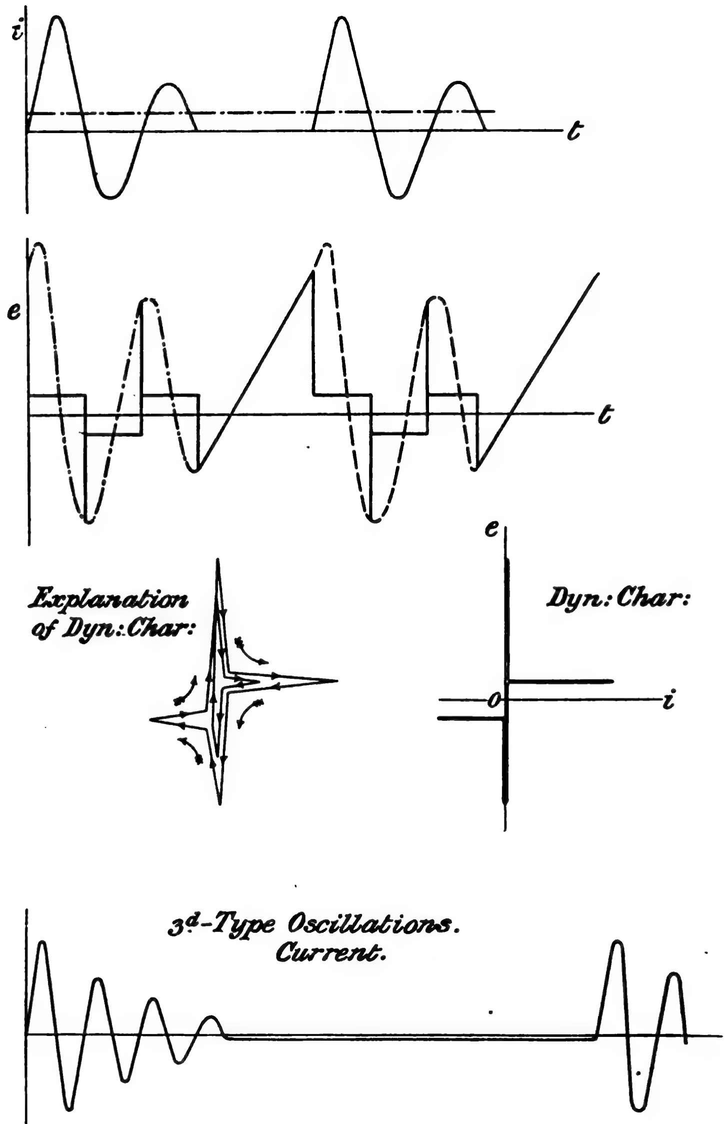


FIG. 8.—Third Type Oscillations.

Before concluding, an interesting little physical experiment * may be mentioned, which in some way confirms the above theories of the oscillating arc, independently of all electrical measurements. The spectrum of an arc in coal-gas or hydrogen was compared, first when the arc was not connected, and secondly, connected to an oscillatory circuit of frequency 277,000 periods per second. In the first case the lines from the copper electrode predominated, while in the second case the lines or bands from the atmosphere were predominant.

* *Physikalische Zeitschrift*, vol. 12, p. 196, 1911.

AN AUTOMATIC STARTING DEVICE FOR ASYNCHRONOUS MOTORS.

By N. PENSABENE-PEREZ, Associate Member.

(*Paper first received* 9*th October*, 1911, *received in final form* 14*th November*, 1911, *and read before the* BIRMINGHAM LOCAL SECTION *on* 13*th December*, 1911.)

SUMMARY.

Induction motors with self-contained resistance—Hand and automatic control—Advantages of the latter—Value of the resistance in function of the speed to maintain a constant-current input—General equation of equilibrium for constant-current automatic starting—Necessity of an independent variable—Variable ratio gear as given by a differential equation—The graphical solution—Condition of proper working—Sensitiveness and the influence of dynamic friction—The fluctuation of current in ordinary multi studs starter—The best theoretical conditions—Time necessary for starting—Energy loss at starting—Comparison with the automatic starting—Mechanical details.

AUTOMATIC STARTING OF ASYNCHRONOUS MOTORS.

The principal advantages of an automatic self-starting induction motor provided with a resistance having a great number of steps can be set forth as follows:—

1. The motor is started by simply closing the primary switch. No mistake in controlling is therefore possible.
2. The motor is always ready to start. If it stops for any reason it can start again, being always protected, and protecting the supply from short-circuit currents. No-voltage release arrangement is never required for the protection of the motor.
3. The motor takes an almost constant current from the supply during the period of starting, with the exception of the first small rush before the contacts begin to move. This involves all the advantages of slow-motion starting control.
4. A constant current equal to the maximum allowable means a considerable reduction in the time necessary for starting.
5. A constant starting current also means a minimum waste of power in the resistances.
6. The motor is very suitable for long-distance control.

7. No brush or slip rings, rotor cables, short-circuiting or brush-lifting device are necessary.
8. Considerable saving as compared with the cost of the slip-ring motor and separate starter.

Let us consider first the problem in its generality. Suppose a suitable arrangement of resistances and moving contacts controlled by centrifugal forces cutting out the resistances from the phases of the motor while the latter increases in speed at starting. Assume that by providing a sufficient number of contacts the resistances are cut out gradually, and that the centrifugal forces moving the contacts are opposed by the action of a spring, which brings back the contacts, and thus inserts all the resistances in circuit, as soon as the speed falls below a certain minimum value.

Let us call s' the slip corresponding to this minimum speed N^1.

If E and r are respectively the rotor electromotive force and the resistance per phase, and R_0 the total starting resistance per phase, it is evident that the current before the rotor begins to move is—

$$i' = \frac{E}{R_0 + r}.$$

This current decreases gradually until it reaches the value—

$$i = \frac{E\,s'}{R_0 + r}.$$

For higher speeds the resistance begins to be cut out, and if we propose to keep the current constant it must be—

$$\frac{E\,s}{R + r} = \frac{E\,s'}{R_0 + r}$$

where s and R are respectively the slip and resistance per phase at any instant.

We have then—

$$s = \frac{N_0 - N}{N_0} = s'\,\frac{R + r,}{R_0 + r}$$

N_0 being the synchronous speed, N the speed corresponding to the slip s; therefore—

$$N = N_0\left(1 - s'\,\frac{R + r}{R_0 + r}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This shows that, in order to keep the rotor, and, in consequence, the stator current constant in the starting period, the resistance of the starter must be varied according to the above relation.

In other words, there must be equilibrium between the centrifugal forces, the tension of the springs, and the friction for any position

corresponding to a certain resistance R and a speed N given by the above formula. The difficulties in the way of the proper solution of this problem are greater than would appear at first sight. Here it will be enough to mention one of a general character.

Suppose we have a system of weights rigidly connected to the moving arms. The centrifugal forces acting on these weights, arms, and contacts are a function of the speed N and of the position of the contacts, which can be defined by a certain length x. Now as N is a function of R, and this is a function of x, we may say that the centrifugal action will be a function of x, say $f_1(x)$. The spring action will be another function, say $f_2(x)$, and, if we call k a constant representing the friction resistance, we must have —

$$f_1(x) = f_2(x) + k$$

for any value of x. Now unless the above be an identity it is impossible to be satisfied for all values of x. The simplest way out of the difficulty is to introduce a new variable y in the shape of a link, or a variable ratio gear between the centrifugal force and the tension of the spring. In this case the relation would be—

$$f_3(x\,y) = f_2(x) + k,$$

and this can always be satisfied for any value of x if we conveniently vary y.

The following is a device, designed by the author, which would fulfil the above condition.* The resistances for a 3-phase wound rotor consist of flat strips wound as three separate independent discs and insulated with asbestos paper (see Fig. 7). These three discs are clamped together with two cast-iron end discs, on the periphery of which is pivoted a bar carrying three arms with three contacts sliding along the polished face of the resistance discs. We may earth the inner extremity of these three resistances and connect the three rotor phases to the other extremity so that when the contacts move outwards they gradually cut out the resistances. In this case the weight of the arms can be used to help the motion of the contacts. When the rotor phases are connected to the inner rings, of course this weight will oppose the motion. This latter arrangement is preferable, as it will be seen later. It is this case we will consider in the following. An auxiliary weight is provided which, through a variable ratio gear, as shown in Fig. 1, produces by centrifugal force the motion of the arms against the tension of the spring.

Let us call $P_1\,l_1$ the moment of this weight and $P\,l$ the moment of the arms and contracts, $\beta_1\ \beta$ the angles as shown in the figure. As soon as the speed of the machine rises above a certain minimum speed the motion begins, and, for a certain position, as indicated in the figure, the

* E.C.C. and Pensabene, Patent No. 13962, 1911.

centrifugal force torques can be expressed in kg. cm. as follows (see Fig. 1):—

$$M_1 = 11{,}2\, P_1\, l_1 \,.\, O\, A_1 \,.\, \left(\frac{N}{1000}\right)^2 \sin\,(\beta_1 + \alpha_1) \quad \text{round } A_1,$$

$$M = 11{,}2\, P\, l \,.\, O\, A \,.\, \left(\frac{N}{1000}\right)^2 \sin\,(\beta - \alpha) \quad \text{round } A,$$

and the torque due to the spring round point A can be expressed as a function S of α.

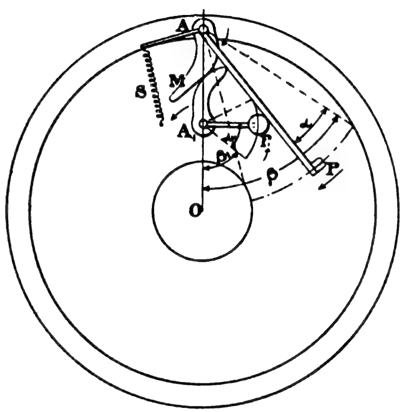


FIG 1.

Finally, if F is the torque due to the friction of the system while in motion, we must have, as stated before, since M opposes the motion—

$$\varepsilon\, M_1 - M = S + F,$$

where ε represents the ratio of the gear for the position under consideration. It is easy to see that—

$$\frac{A\,M}{A_1\,M} = \frac{d\,\alpha_1}{d\,\alpha};$$

so it is—

$$11{,}2\, P_1\, l_1 \,.\, O\, A_1 \,.\, \left(\frac{N}{1000}\right)^2 \sin\,(\beta_1 + \alpha_1)\, \frac{d\,\alpha_1}{d\,\alpha}$$

$$- 11{,}2\, P\, l \,.\, O\, A \,.\, \left(\frac{N}{1000}\right)^2 \sin\,(\beta - \alpha) = S + F \quad . \quad . (2)$$

Now N is given by (1) where R is a function of α, so the above is really a differential equation having variables α_1 and α easily separable.

It is, therefore, simple to express a_1 in function of a and, in consequence, to find—

$$\epsilon = \frac{d\,a_1}{d\,a}$$

for any value of a. In this way it will be possible to find the shape of the gear by which the equation (2) can be satisfied. An analytical solution, however, leads to complicated expressions of difficult application.

The following is a graphical treatment, which I think is far prefer-

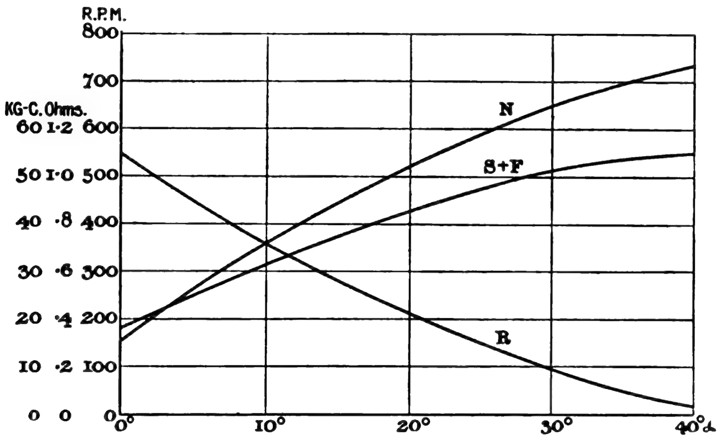


FIG. 2.

able, as, apart from being simpler, it gives a clearer insight into the bearing which the different elements have in the problem.

Equation (2) can be written—

$$\sin\,(\beta_1 + a_1)\,\frac{d\,a_1}{d\,a} = \left(\frac{S + F}{13\,P_1\,l_1\left(\frac{N}{1000}\right)^2 O\,A_1}\right.$$

$$\left. + \frac{P\,l\,O\,A}{P_1\,l_1\,O\,A_1}\sin\,(\beta - a)\right) = \phi(a) \quad . \quad . \quad . \quad (3)$$

In the annexed diagram (Fig. 2) we have plotted with the angle a as abscissæ the value of resistance R and the speed N given by the equation (1). With the help of this last curve the second member of the above expression can be easily plotted (Fig. 3). This is a curve shown in the diagram as $\phi(a)$; by integration of (3) we get—

$$\int_0^{a_1} \sin\,(\beta_1 + a_1)\,d\,a_1 = \int_0^{a} \phi\,(a)\,d\,a.$$

The integral curve of the second member can be easily traced and, in consequence, also—

$$\cos(\beta_1 + a_1) = \cos\beta_1 - \int_0^a \phi(a)\, d\, a$$

and—

$$a_1 = \text{arc}\cos\left(\cos\beta_1 - \int_0^a \phi(a)\, d\, a\right) - \beta_1,$$

which gives the angle a_1 in the terms of the angle a. This has been

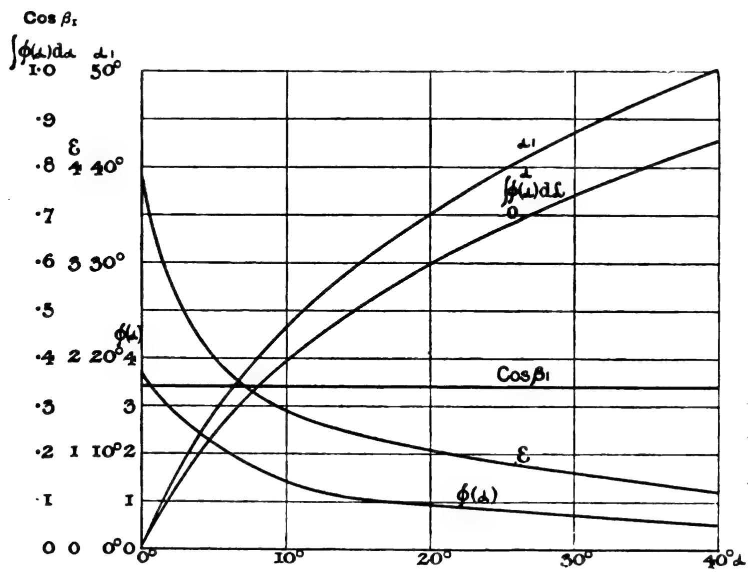


FIG. 3.

plotted in the diagram. As we have said before, the value of ε is given by—

$$\varepsilon = \frac{d\, a_1}{d\, a} = \frac{\phi(a)}{\sin(\beta_1 + a_1)},$$

which is simply the coefficient of the tangent at any point of the curve a_1. It is obvious that for the proper working of the gear the ratio must decrease with a. Therefore, we come to the following condition: The curve ε must not admit any maximum or minimum for any value of a between zero and a_0.

In Fig. 3 a curve has been plotted giving ε in terms of a. From this it is easy to trace the shape of the gear as shown in Fig. 4. It will be

seen that the fingers A, B engage at normal running conditions, and the ratio being thereby increased the speed can go down to any pre-arranged value before any backward motion can take place.

Reliability in Working.

When experimenting with the apparatus described, serious faults were found to exist, and were at first very difficult to explain and eliminate. As soon as the primary switch was closed, the stator current reached the maximum calculated, but this gradually went down considerably below the constant value pre-arranged, after which, if the load exceeded a certain value, the motor stopped accelerating, and, if the load was reduced, the motor suddenly went up to full-load speed after a considerable rush of current. To understand what was taking place we must introduce another factor, that is the difference between the static and dynamic friction, or what can be termed the sticking action. The influence of this element can be seen from the following. As soon as the primary switch is closed the current through the resistance will be i'. The motor begins to accelerate more or less quickly according to the load. When the speed N′ is reached the current will take the value equal to $i = s' i'$, which we propose to keep constant during all periods of acceleration. At such a speed there is an equilibrium between the centrifugal force, tension of the spring, and the dynamic friction F. If, however, the static friction is n F, where n is a number larger than unity, the speed necessary to produce the starting motion will be m N′ given by the relation—

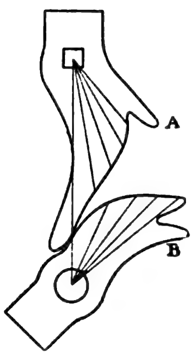


Fig. 4.

$$\frac{\varepsilon M_1 - M}{N'^2} (m N')^2 = S + n F,$$

where M_1 M S are calculated for $a = 0$.

As we have arranged to have $\varepsilon M_1 - M = S + F$ we have—

$$m = \sqrt{\frac{S + n F}{S + F}} = \sqrt{1 + \frac{n - 1}{1 + \frac{S}{F}}}$$

which shows that in order to reduce the increase of speed necessary to overcome the difference between static and dynamic friction, the ratio between the spring tension and the static friction must be as large as possible. As soon as the motion is initiated the friction drops to the dynamic value, and there is an excess of motive effort, and, in consequence, acceleration until the contacts have assumed that position in which the spring balances the action of the centrifugal forces. In his position the contacts stop again. We may assume that the time

taken by the contacts to move and stop again is so small as to warrant our considering the speed of the motor constant in this period equal to $m\,N'$. The position, then, the contacts are going to take can be easily fixed, being the position for which there is equilibrium at such a speed in the case of dynamic friction. The process continues in the same way. Now it is obvious that while the contacts are stationary on the discs, and the speed increases, the current and the torque of the motor goes down, and may fall to such a value as to reach the magnitude of the load torque, in which case the motor stops accelerating.

When the increase in speed necessary to overcome the static friction exceeds a certain limit, it is obvious that the acceleration of the contacts and arms, etc., may be so great as to store enough kinetic energy in the system as to make the contacts overstep the angle of equilibrium corresponding to the speed of the motor, hence a current larger than i. Near synchronism this danger is more pronounced, and large kicks of current were observed, showing that all the resistances were cut out too soon. All these troubles have been practically eliminated by reducing the friction F as much as possible, and increasing the spring tension.

Time necessary for Starting.

The time necessary for starting a motor depends on the magnitude of the accelerating torque (that is, the torque difference between the motor torque and the load torque) and the kinetic energy stored in all the masses driven by the motor at full speed. In any motor controlled by an ordinary starter the current and the torque fluctuate between a maximum and a minimum value, and this fluctuation is the greater the smaller the number of contacts in the starter. In the case of the automatic starter, the number of steps being very great, the current would drop, as we have seen, down to 80 per cent., or 75 per cent. of the maximum allowed, and then remain practically constant until the machine reaches full speed. For this reason the time taken by the automatic starter, as described, is much less than the time taken by a motor controlled by an ordinary commercial starter. In the following is described a graphical method of calculating the time necessary for starting, and the advantage, as set forth above, of a starter with a very large number of contacts will be clearly shown. This calculation, however, does not take into consideration the human factor in the case of the hand control, by which it is extremely difficult to satisfy the theoretical conditions necessary to obtain the best results.

In general, if we call H the accelerating brake-horse-power after t seconds from the moment the motor begins to move, and w the stored energy in horse-power seconds, we have—

$$H\,d\,t = d\,w.$$

Now we can write—

$$w = W\,\frac{N'^2}{N^2},$$

where W is the stored energy at full speed N, and N′ the speed at the instant in consideration. We have also—

$$H = \frac{T\,N'}{725},$$

where T is in kg. m. the accelerating torque, therefore—

$$\frac{T\,N'\,dt}{725} = 2\,\frac{W}{N^2}\,N'\,d\,N'$$

or, finally—

$$t = \frac{1450}{N^2}\,W \int_0^N \frac{d\,N'}{T}$$

in seconds.

It will be noted here, by the way, that the accelerating torque T in a motor is never nil, because the time necessary to reach the speed for which it becomes nil is infinite. An induction motor, for instance, even if working against zero load torque (no friction or hysteresis torque, etc.), will never reach synchronism if provided with inertia. The physical explanation of this can be easily conceived.

Let us now consider first the case of a n coil starter, and let us assume the current in the rotor to be limited to the value I_2. If this current is not much greater than the current corresponding to the maximum power factor, we can assume the rotor flux to be constant and equal to the stator flux, and, therefore, we can take the rotor current to be approximately proportional to the torque developed by the motor. The current I_2 after starting will go down, and so will the torque as soon as the rotor begins to increase in speed. If the minimum torque is fixed, and corresponding to the current I_1, as soon as this current is reached, we must pass to the next contact, where the current will jump again to the maximum value I_2, and so on.

If E is the rotor E.M.F., and $r_n, r_{n-1} \ldots r_1$ the resistances on different steps, $s_n, s_{n-1} \ldots s_1$, the slips at the end of each step, r the rotor resistance and s the slip produced by this resistance at the load I_1, we have—

$$I_2 = \frac{E}{r_n} = \frac{E\,s_n}{r_{n-1}} = \ldots = \frac{E\,s_1}{r}$$

$$I_1 = \frac{E\,s_n}{r_n} = \frac{E\,s_{n-1}}{r_{n-1}} = \ldots = \frac{E\,s}{r},$$

therefore—

$$\frac{I_2}{I_1} = k = \frac{1}{s_n} = \frac{s_n}{s_{n-1}} = \ldots \frac{s_1}{s} = \frac{r_n}{r_{n-r}} = \frac{r_{n-1}}{r_{n-2}} = \ldots = \frac{r_1}{r},$$

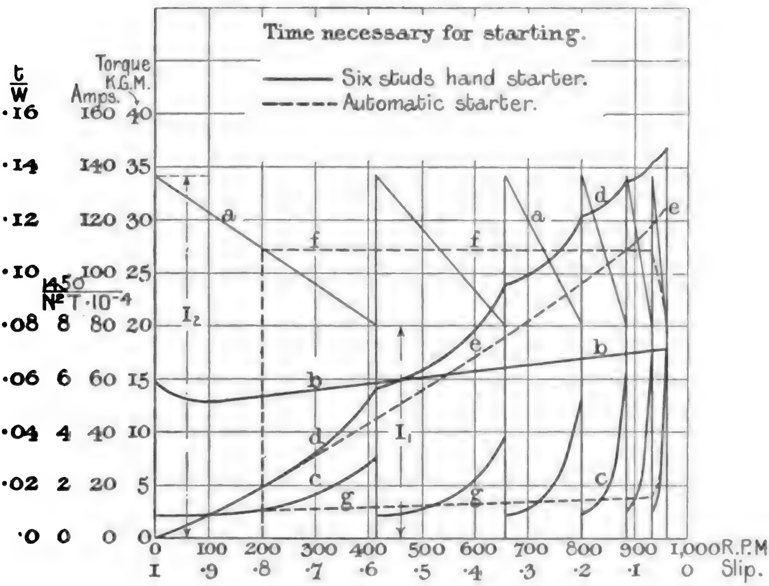
or—

$$1 = k\,s_n,\quad s_n = k\,s_{n-1} \ldots s_1 = k\,s,$$

or—

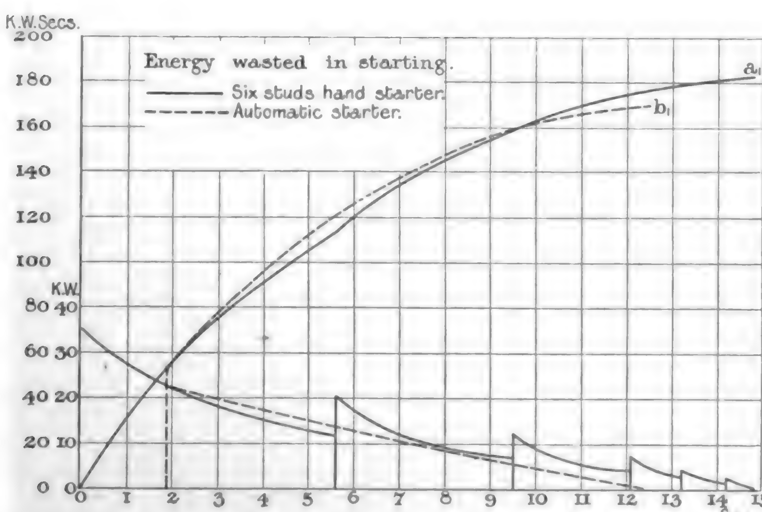
$$r_n = k\,r_{n-1},\quad r_{n-1} = k\,r_{n-2} \ldots r_1 = k\,r \text{ and } k = \sqrt[n+1]{\frac{1}{s}} = \sqrt[n]{\frac{r_n}{r}}.$$

$n + 1$ is the number of studs used in the starter after the motor begins to move, n is the number of starting resistance coils.



Time necessary for starting.
Six studs hand starter.
Automatic starter.
t/W
Torque K.G.M.
Amps.
1450/N² T·10⁻⁴
·16 160 40
·14 140 35
·12 120 30
·10 100 25
·08 8 80 20
·06 6 60 15
·04 4 40 10
·02 2 20 5
·0 0 0 0
0 100 200 300 400 500 600 700 800 900 1,000 R.P.M.
1 ·9 ·8 ·7 ·6 ·5 ·4 ·3 ·2 ·1 0 Slip.
a
b
c
d
e
f
g
I₂
I₁

FIG. 5.



K.W.Secs.
Energy wasted in starting.
Six studs hand starter.
Automatic starter.
K.W.
200
180
160
140
120
100
80 40
60 30
40 20
20 10
0 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Secs.
a₁
b₁

FIG. 6.

Let us consider the case of a 25-B.H.P. induction motor controlled by a six-stud starter.

Let us plot in Fig. 5 the load torque as given by curve *b* in function of the speed or slip. Let us fix as minimum torque to be developed by the motor the torque corresponding to I_1, then—

$$I_2 = I_1 \sqrt[6]{\frac{1}{s}};$$

assuming $s = 0{\cdot}04$, we get—

$$I_2 = 1{\cdot}71\, I_1, \quad k = 1{\cdot}71.$$

In the first step the slip goes from unity to $\frac{1}{k} = \frac{I_1}{I_2}$, in the second step from $\frac{1}{k}$ to $\frac{1}{k^2}$, etc. By taking the segment O O as unity, the slip at the end of any step can be fixed as in the figure. The current in each step varies as a straight line from I_2 to I_1.

The torque T is evidently the difference of the ordinates of curve *a*, which represents the motor torque and the curve *b*, which represents the load torque.

To find the time it will now be necessary to plot the curve *c* representing the values—

$$\frac{1450}{N^2} \cdot \frac{1}{T},$$

and by integrating this we can plot curve *d* with the values given by—

$$\frac{t}{W} = \frac{1450}{N^2} \cdot \int_0^{N'} \frac{d\,N'}{T},$$

or seconds per horse-power stored energy, necessary to reach any speed between O and N.

The same process can be repeated for the case of automatic control. In this case, if we keep the same maximum current I_2, the constant current will be $s' I_2$, where s' is the slip (in our case assumed to be equal to $0{\cdot}8$) at which the resistance begins to be cut off. This constant current, or torque, will be represented by curve *f*.

The expression $\frac{1450}{N^2} \frac{1}{T}$ will be here expressed by the dotted curve *g* and the integral, or $\frac{t}{W}$ by curve *e*.

It will be seen here that the time per horse-power seconds stored energy is considerably less than with the hand control in the best theoretical conditions of a six-stud starter.

Moreover, the losses in the resistance are less, as can be seen in Fig. 6. In this figure we have plotted in terms of time the expressions $3\, I^2 r$ in the assumption of 100-H.P.-seconds stored energy; the full

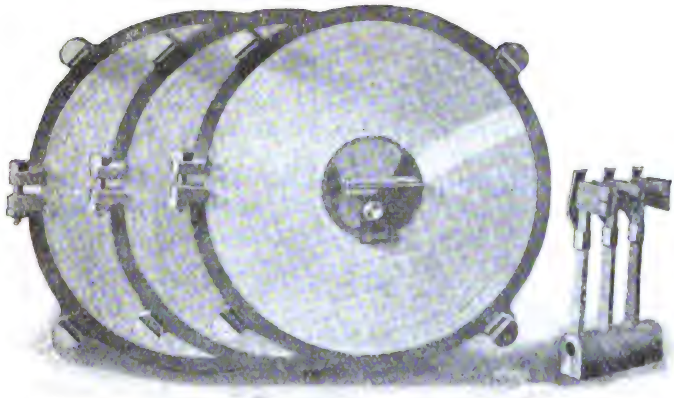


FIG. 7.

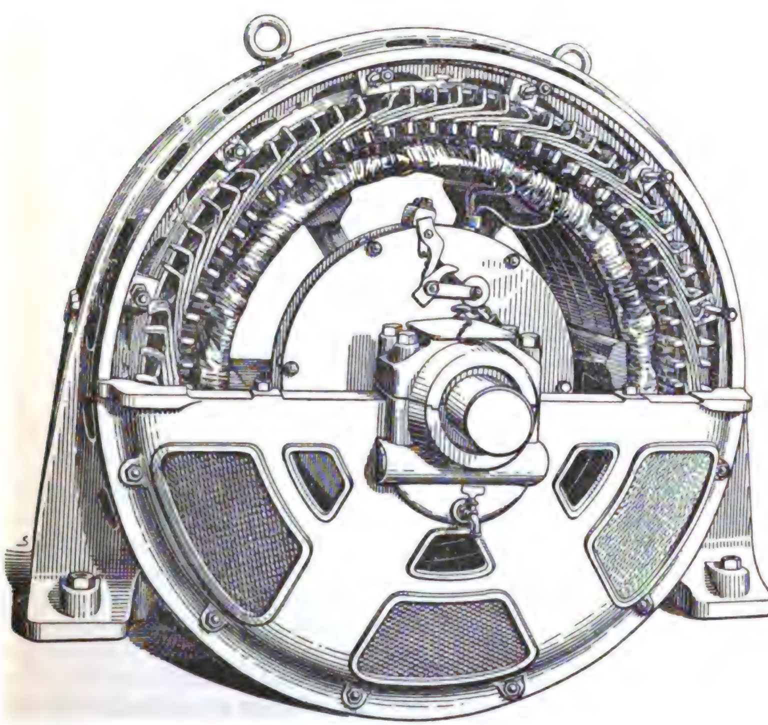


FIG. 8.

line belonging to the first case and the dotted line to the self-starting case.

The curves $o\,a_1$ and $o\,b_1$ represent the kilowatts lost at any instant in one and the other case.

Fig. 7 shows details of a 20-H.P. automatic starter. It is to be noted that besides the asbestos paper between turns of the spiral German silver strip no other insulating material is used. This can only be achieved by making the outside cast-iron rings, which clamp each resistance ring, the neutral of the starter, which, therefore, is earthed. The inside rings of the discs are connected to the end of the rotor phases. The weights of the contacts and arms act against the motion. Although this is an inconvenience, the little disadvantage is amply repaid by the simplicity and soundness of the construction.

Fig. 8 shows a 300-H.P. induction motor made by the Electric Construction Company, Ltd., fitted with a self-contained automatic starter. This was designed to start the motor against one-third of full-load torque. This starter is fixed on the arms of the spider, and, the three phases being connected to the outside of the discs, the contacts move outwards. A starter of this description is specially suitable for high-voltage induction motors, as it entirely avoids any danger of large rush of current at starting due to carelessness in cutting out the starting resistance. These large fluctuations of current, as is well known, are very often responsible for surging effect, producing breakdown in the high-tension windings.

Discussion.

Mr. Forster.

Mr. A. Lindsay Forster: On page 490 the author refers to certain difficulties which had to be overcome in the development of the details. These difficulties suggest that the author might have had some trouble arising out of the effect of the inertia of the moving parts. In designing steam engine governors in which the operating weights are on axes parallel to the rotating shaft it was necessary to consider the effect of any change in the rate of motion because such change affected the equilibrium established between the centrifugal force of the weights and the spring which opposed it. In Fig. 1 of the paper, if a line is drawn from the shaft centre through the centre of gravity of the weight in any position, and another line normal to it also passing through the same point, would be the one along which inertia and momentum would act in their respective directions during any change in the rate of motion. If this line did not pass through A, the fulcrum and then the weight itself would be affected by such changes, but in any other position the effect of these changes would be directly proportional to the distance of the line from the fulcrum A. In the diagram the weights while at their inmost position would be unaffected by these forces, but as they moved outwards the influence of any increase in the speed of the motor would oppose the centrifugal force, whereas a reduction in speed while the change was in progress would assist the

centrifugal force. Similar reasoning applies to all the moving masses in the governor system. In Fig. 1, for example, the weight of the brush-arm while centrifugally opposed to that of the governor weight, acts in unison with it with regard to inertia and momentum. If the direction of rotation is reversed the above effects will be reversed, and it would be interesting to know whether the author has found that with a reversible motor a difference between the performances in the two directions can be noticed. When starting a machine which offers a constant torque these effects would not be of as much importance as they might be where the torque is variable, under which conditions the rate of acceleration would also be variable. Mr. Forster.

Dr. C. C. GARRARD: The author's invention should find many useful applications, especially where 3-phase motors are to be started by totally unskilled people or by people who knew nothing about electricity, such as would be the case when motors were installed for isolated machinery. I do not think the apparatus will supersede the ordinary starter in large works where the motors are usually started by a skilled person; I also doubt whether the apparatus is cheaper than slip-rings and a rotor starter. The usefulness of the paper appears to me to have been limited by the author by his unnecessarily mathematical treatment. No doubt the author found the mathematical investigation of use; that it is limited in this case in its application is admitted on page 488, where he says: "The analytical solution leads to complicated expressions of difficult application," and then he proceeds to use a graphical method. Moreover, a long mathematical proof is not needed to demonstrate that the ratio between spring tension and static friction must be as large as possible, or that all these troubles have been practically eliminated by reducing the friction as much as possible as stated on pages 490 and 491. In order to achieve success in any electro-mechanical appliance, from an ammeter upwards, it is necessary to keep the working forces large in comparison with the friction. I should like to ask the author how his device would work if the conditions were different from those assumed when calculating the resistance slope of gearing, etc. With the ordinary scheme of self-starting and automatic accelerating control gear means are provided, by the use of a relay or other device, that the speed of starting and the time taken to cut out the various steps of resistance can adapt themselves to the conditions of starting. With the author's device a certain speed corresponds to a fixed position of the centrifugal arrangement, which puts a fixed resistance in the rotor circuit independently of the torque required to drive the load at that speed. It seems to me that if the starting conditions were very different from those allowed for in the design complications might arise, and I should be very glad if the author would enlighten me on this point. Dr. Garrard.

Mr. N. PENSABENE-PEREZ (*in reply*): I am much obliged to Mr. Lindsay-Forster for calling attention to the action of inertia of the moving parts as affecting the equilibrium of the system, when sudden variation of speed took place. In actual practice these variations Mr. Pensabene-Perez

Mr. Pensabene-Perez. (owing to the inertia of the motor itself and the machinery driven by it) are too slow and the stored energy of the moving weight too small, for the effect mentioned by Mr. Forster to become noticeable. I have recently tried the case of a self-starting motor driving a dynamo fully excited on which the current was suddenly varied while starting, but no special fluctuation of the motor-starting current was observed owing to this sudden change of load torque. This was found to be the case when running in either direction. It must be noted that with the exception of the moving weight, all the weights of the arms, gear, etc., are balanced, and this explains partly why the phenomena mentioned by Mr. Forster are not noticeable in practice. With reference to Dr. Garrard's remarks, I cannot agree with him that in larger motors handled by skilled persons the usual slip-ring motor and starter could not be superseded by the self-starting motor. It is, of course, only reliability and cheapness which in time would decide this point, and from either of these points of view the balance was in favour of the automatic self-starting motor. Dr. Garrard's reference to the use of mathematics in the paper gave the author a strong suspicion that he was under a misapprehension on this point. If Dr. Garrard was kind enough to read the paper again he would notice that no unnecessary mathematics is used, and that all the formulæ arrived at were necessary for the graphical solution given in the paper. Dr. Garrard seemed to think that the "analytical solution which leads to complicated expressions of difficult application" had been developed in this paper, while this was not the case, formula (2) being only the differential equation which had to be solved. This was done, only by a graphical method. Moreover, no long mathematical formula was given to prove that the ratio between spring and static friction must be as large as possible. The simple formula given gave the value of the increase in speed necessary to overcome the difference between static and dynamic friction. With reference to the remarks of Dr. Garrard as to adaptability of the self-starting motor to the different conditions of starting, I should like to say that in cases where the load torque expected is smaller than the actual torque to deal with, the apparatus described could be easily adjusted by a simple arrangement which would prevent the contacts going all the way back under the action of the spring. By this means only a fraction of the resistance is used for starting, and thus a larger starting torque is obtained. This would answer satisfactorily for ordinary practical requirements.

THE DEVELOPMENT OF THE CIRCLE DIAGRAM FOR THE THREE-PHASE INDUCTION MACHINE.

By THOMAS F. WALL, M.Sc., M.Eng., Associate Member.

(*Paper first received* 13*th July*, 1911, *received in final form* 5*th December*, 1911, *and read before the* BIRMINGHAM LOCAL SECTION *on* 13*th December*, 1911.)

The development of the circle diagram given in the following is, as far as the author is aware, to some extent new, and it is believed that it will be found to be exceedingly simple.

The operation of one phase only will be considered, for the action of each phase will be identical.

In Fig. 1 the resultant rotating field due to the current in a 3-phase stator winding is shown in full lines, and for that instant at which the current in phase 1 has a maximum value. The current in phase 1 is considered positive when the current in the conductor marked 1 is as indicated by ⊗. It is to be noted that the rotating field is wholly linking the coils of phase 1, so that at this instant the conductors of this phase are not being cut by any lines of force. The conditions, therefore, represented by Fig. 1 are such that the current in phase 1 is a maximum, and the flux cutting the conductors of this phase is zero. Hence, if the current in phase 1 be represented by a vector, the vector of the rotating field must be drawn at 90° to this current vector. The vector of the rotating field will be drawn to coincide in direction with the E.M.F. which it induces.

Fig. 2 shows the position of the resultant rotating field relatively to the stator conductors for the instant $\frac{1}{12}$ of a period earlier than that to which Fig. 1 refers. The current in phase 1 is positive and increasing, and the flux cutting the conductor 1 of this phase produces a negative and decreasing E.M.F. in this phase, therefore the current vector is to be drawn in advance of the flux vector. It has been shown above that the phase displacement between the current vector and the flux vector is 90°, hence the current vector is to be drawn 90° in advance of the rotating field. It may be remarked here, that part of the flux produced by the current in phase 1, *e.g.*, the slot leakage flux, does not combine with the flux due to the current in the coils of the other phases to produce a rotating field. Since, however, this part of the flux is pulsating, the E.M.F. produced by it is 90° behind the current, and has therefore the same phase as the E.M.F. produced by the rotating field.

This pulsating flux may be taken into account, therefore, by correspondingly increasing the vector of the rotating field.

The vector diagram may now be drawn, always remembering that

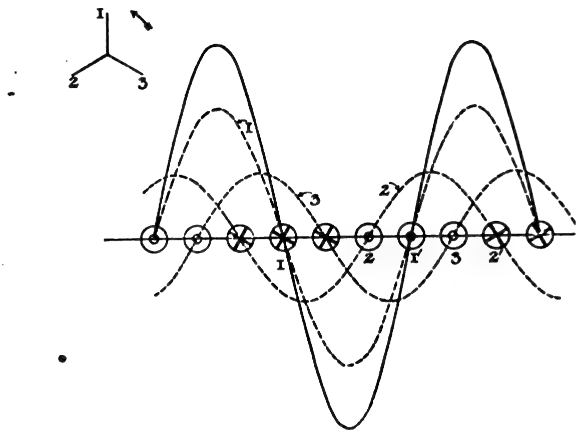


FIG. 1.

the rotating field lags by 90° on the corresponding current in any one phase. It is convenient when drawing the vector diagram, to consider the rotor winding as having the same number of active conductors in

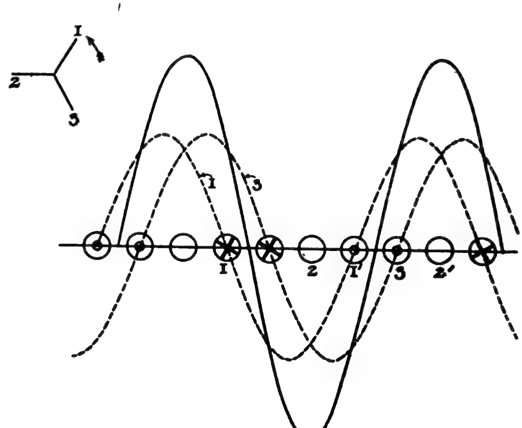


FIG. 2.

series per phase as the stator winding, that is to say, if q_1 be the number of active conductors in series per phase in the stator winding, and q_2 be the number of active conductors in series per phase in the rotor wind-

ing, the number of active conductors in series per phase of the rotor winding is assumed to be increased in the ratio q_1/q_2, and the rotor current diminished in the same ratio. The winding factors of both windings are assumed to be the same.

In Fig. 3 let O D be the vector of the effective value of the rotating field due to a current in the stator winding of effective value I_1 per phase. Let O D_1 be the effective value of the vector of the part of this rotating field which links the rotor windings. Let $OD = OD_1 (1 + \lambda_1)$. Let O C and O C_1 be similar vectors for the rotor windings, and call $OC = OC_1 (1 + \lambda_2)$. Then O E will be the resultant vector of the rotating field cutting the stator windings, and O A_1 will be the vector of the total field cutting the rotor windings.

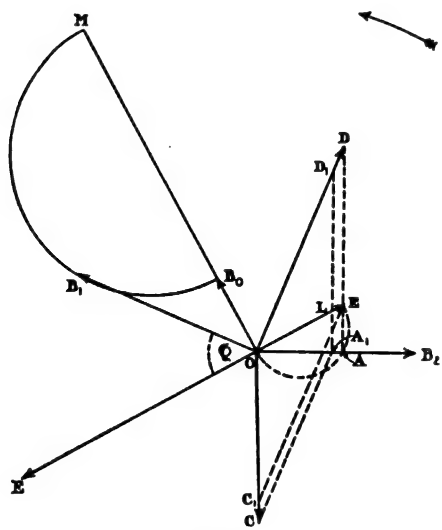


FIG. 3.

In what follows, the applied pressure at the stator terminals is considered constant, and in the first place it will be assumed that the resistance of the stator winding is negligibly small. It is at once seen that the vector O E must be of constant magnitude.

Now it is clear that the rotor current must be in phase with the actually existing rotor flux cutting the rotor winding, *i.e.*, in phase with O A_1. According to the previous argument, the vector of the stator current (O B_1 in Fig. 3) must be drawn 90° in advance of O D, and the vector of the rotor current (O B_2 in Fig. 3) must be drawn at 90° in advance of O C. Hence O A must be at right angles to O C. Now, since O E is of constant magnitude, and the angle E A O is 90°, the point A must move over a circle on O E as diameter. Further, since D E is proportional to E A (see below), it follows that D must move over

a circle whose diameter lies on O E produced. The following relations then hold:—

$$E A = D A - D E;$$

$$D A / D_1 A_1 = O D / O D_1;$$

$$\therefore \quad D A = O C . \frac{O D}{O D_1};$$

$$i.e., \ D A = D E (1 + \lambda_2) \frac{O D}{O D_1} = D E (1 + \lambda_2)(1 + \lambda_1);$$

$$\therefore \quad E A = D E [(1 + \lambda_1)(1 + \lambda_2) - 1].$$

Hence the diameter of the circle over which D moves—

$$= O E / [(1 + \lambda_1)(1 + \lambda_2) - 1].$$

In Fig. 3 the vector O B_0 represents the current corresponding to the flux O E—*i.e.*, the magnetising current. It is evident that the extremity of the vector of the stator current O B_1 must move over a circle whose centre lies on O B_0 produced, and whose diameter is—

$$O B_0 / [(1 + \lambda_1)(1 + \lambda_2) - 1];$$

for the reluctance of the magnetic circuit is considered constant, and therefore the current is proportional to the flux which it produces.

The torque of the motor is given by the product of the rotor current, and that component of the flux due to the stator current which is in phase with the rotor current. Hence the torque—

$\equiv O B_2 . O A_1 \equiv E D . O A \equiv B_0 B_1 . M B_1 \equiv$ area of triangle $B_0 B_1 M \equiv$ * the height of the extremity of the current vector above the diameter of the circle. In Fig. 4 the current circle diagram is shown without the vectors of flux. The torque is represented by the distance $B_1 N$.

Remembering that, for the present, the stator resistance is neglected, it is clear that the mechanical power developed by the motor is given by the input minus the I^2R losses in the rotor winding. If O B_1 represents the stator current, the ordinate $B_1 N$ will represent the stator input, since the applied pressure is constant. The vector $B_0 B_1 (1 + \lambda_1)$ will represent the rotor current (reduced, of course, to the stator turns). Now in the similar triangles—

$$B_0 B_1 N : B_0 M B_1;$$

$$B_0 N / B_0 B_1 = B_0 B_1 / B_0 M;$$

$$\therefore \quad B_0 B_1^2 = B_0 N . B_0 M.$$

But U N is proportional to $B_0 N$—*i.e.*, to the square of the rotor current. When B_1 coincides with the short-circuit point B_S the whole of the stator input $B_S R$ is the rotor I^2R loss. Hence $B_1 U$ is proportional to the stator input minus the I^2R losses in the rotor winding—*i.e.*, $B_1 U$ is proportional to the developed horse-power of the motor.

* The sign $\equiv$ is used to indicate "is proportional to."

In order to obtain the representation of the slip on the circle diagram the following relationships may be noted: The torque exerted on the rotor multiplied by the speed of the rotating field—*i.e.*, by the synchronous speed—gives the power supplied to the rotor. The product of the torque and the rotor speed gives the mechanical power developed by the rotor. Hence the difference of the two, viz., the product of the torque and the rotor slip, gives the power lost in the rotor windings. Since the rotor iron losses are negligibly small (the slip being small) the rotor losses can be considered as purely I^2R losses. Hence—

$$\text{Torque} \times \text{slip} = \text{rotor } I^2R \text{ loss};$$

therefore—

$$\text{Slip} = \text{constant } \frac{U\,N}{B_1\,N}$$

since the torque is represented by $B_1\,N$.

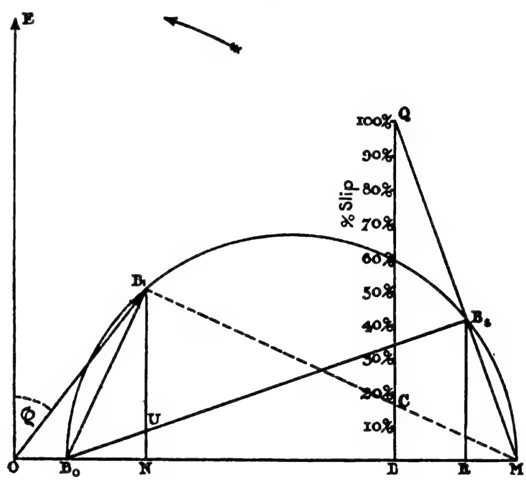


FIG. 4.

Join M B_S and produce, and from any point Q in M B_S produced, draw Q D at right angles to O M. Let C be the point of intersection of the lines Q D and M B_1. The triangles M C D and $B_1\,B_0\,N$ are similar, and the triangles M Q D and U B_0 N are similar, therefore—

$$\frac{U\,N}{N\,B_0} = \frac{M\,D}{D\,Q}; \quad \frac{C\,D}{M\,D} = \frac{N\,B_0}{N\,B_1};$$

$$\therefore\; C\,D\,.\,N\,B_1 = U\,N\,.\,D\,Q;$$

$$C\,D = D\,Q\,.\,\frac{U\,N}{B_1\,N},$$

Hence C D is proportional to the slip.

In the practical case it is not sufficiently accurate to neglect the stator resistance in so far as the power is concerned, and it therefore becomes necessary to examine the influence of the stator resistance on the construction of the circle diagram, and on the torque, power, and slip lines. The stator resistance will still be assumed to be so small that the stator flux—*i.e.*, the vector O E in Fig. 3—remains constant, and consequently the vector diagram of Fig. 3 is unaltered. In Fig. 5 let B_S be the short-circuit point, then $B_S R$ represents the power supplied to the motor at short circuit, and since the motor is at rest all the power supplied must be consumed in I^2R losses and iron losses. The iron losses may be taken into account in the vector diagram by drawing

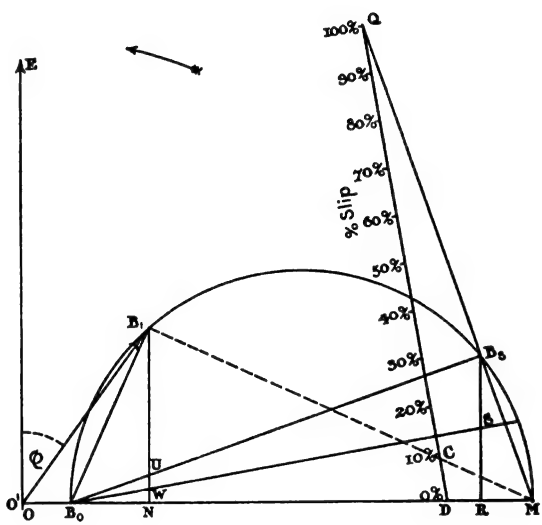


FIG. 5.

from O′ a line O′ O vertically downwards to a distance which represents the current per phase necessary to supply the iron losses. The iron losses are assumed to be constant, and if the point O be taken as the origin for the stator current vectors instead of O′, the circle diagram will give the total stator current per phase.

The distance $B_S R$ in Fig. 5 represents the I^2R losses in the stator and rotor windings. Supposing the stator current vector is assumed to be given by $B_0 B_1$ instead of by $O' B_1$. It has been shown already that the distance $B_0 N$ is proportional to $B_0 B_1^2$. Therefore if $B_S R$ represent the total I^2R losses at standstill, U N will represent the I^2R losses when the stator current is $O' B_1$ (because it is assumed that $O' B_1 = B_0 B_1$). The assumption involves the neglect of the I^2R loss due to the magnetising current $O' B_0$. Hence for any point B_1 on the current circle, U N may be taken to represent the total I^2R losses. The

distance $B_1 N$ represents the total power supplied to the motor less the iron loss. The distance $B_1 U$ will represent, therefore, the mechanical power developed. This will not represent the power available at the motor pulley, because the friction must be subtracted first.

The torque is determined from the power supplied to the rotor, for it has been shown previously that the power supplied to the rotor is equal to the torque multiplied by the synchronous speed of the motor. The synchronous speed is, however, a constant quantity, and the torque is therefore proportional to the power supplied to the rotor. Suppose that the distance $B_S R$ is divided in the ratio of the stator resistance to the rotor resistance (reduced to the stator turns)—*i.e.*, so that SR represents the stator resistance and $S B_S$ represents the rotor resistance. Then it is easy to see that for any point on the current circle UW will represent the rotor I^2R losses, and WN will represent the stator I^2R losses. Hence $B_1 W$ represents the power supplied to the rotor—*i.e.*, $B_1 W$ represents the torque of the motor.

To obtain the slip, let $M B_S$ be produced to any distance MQ, and from Q draw QD at right angles to $B_0 S$. Then the triangles $B_1 W B_0 : MDC$ are similar. Also the triangles $MQD : U B_0 W$ are similar. Therefore—

$$\frac{B_1 W}{W B_0} = \frac{MD}{DC}; \quad \frac{MD}{DQ} = \frac{UW}{W B_0}.$$

$$\therefore \; B_1 W . DC = UW . DQ.$$

$$\therefore \; DC = \frac{UW}{B_1 W} . DQ.$$

It has been stated already that the rotor I^2R loss is given by the product of the torque and the slip—*i.e.*, UW is proportional to the product of B_1W and the slip. Therefore the slip is proportional to UW/B_1W. But it has been shown that $\frac{UW}{B_1W}$ is proportional to DC. Hence DC is proportional to the slip.

An example of the use of this diagram will show what degree of accuracy may be expected. A test was made on an 8-B.H.P. 3-phase induction motor. The test data were as follows :—

Open Circuit.

The rotor running light with short-circuited windings.

$E = 200$ volts. $I_0 = 3{\cdot}93$ amperes per phase.
$\cos\phi_0 = 0{\cdot}19$. Frequency $(\nu) = 50$ cycles per second.

Short Circuit.

$I_s = 44{\cdot}8$ amperes per phase reduced to an applied pressure of 200 volts.
$\cos\phi_s = 0{\cdot}336$. Frequency $(\nu) = 50$ cycles per second.

The friction loss was obtained by the well-known method of running the motor with various applied pressures, starting from a high value and gradually reducing pressure, and measuring the input to the stator. If this input (less the stator I^2R loss) be plotted against the applied pressure, and the curve so obtained be produced backwards to the axis of power, the intercept will give the friction loss. The pulsation losses due to the stator and rotor teeth will be equivalent to an apparent increase of the friction loss. The pulsation loss will, however, be generally small, and need not therefore be taken into account. This loss can be found by the method given in a previous paper * by the author.

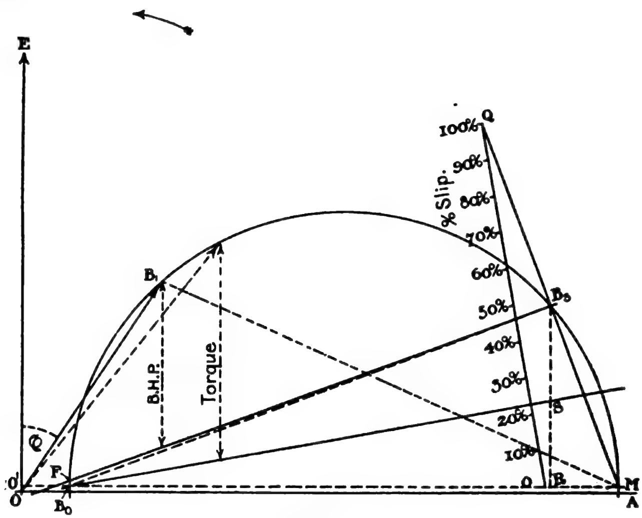


FIG. 6.

The iron loss in the stator is obtained from the no-load input after subtracting the power for friction.

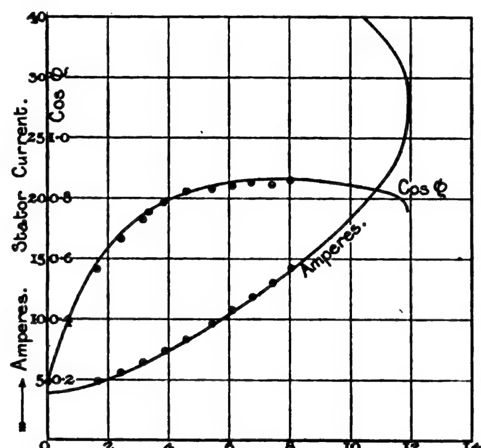
Fig. 6 has been drawn from the above test data. From the point O the watt component of the no-load current representing the iron losses is drawn as at O O'. From O' the magnetising current O' B_0 is drawn. The point B_0 of the circle diagram is thus obtained. From O the short-circuit current 44·8 amperes per phase is drawn, and this gives a second point B_S on the current circle. The centre of the circle lies on O' B_0 produced, and therefore the circle may now be drawn. The line B_S R is divided in the ratio of stator resistance to the rotor resistance (reduced to the stator turns). The stator resistance was 0·72 ohm, and the reduced rotor resistance 0·78 ohm. Therefore $SR/SB_S = 0{\cdot}924$. In general, the reduced rotor resistance is very nearly equal to the stator resistance, and it is therefore generally sufficient to bisect the line B_S R.

* *Electrician*, vol. 59, p. 374, 1907.

In order to obtain the B.H.P. from the diagram an allowance must be made for friction. This may be done as follows: The current per phase necessary to overcome the friction is drawn from B_0 vertically upwards as shown in the Fig. 6. The short-circuit point B_S is joined to F, and the line $B_S F$ is taken to represent the B.H.P. line.

In Fig. 7 the B.H.P. has been plotted as abscissa, and the values of the stator current and the power factor have been plotted as ordinates. The full-line curves have been plotted from the circle diagram as shown in Fig. 6, and the points marked ⊙ were taken in an actual B.H.P. test.

As regards the agreement between the B.H.P. test figures and those deduced from the circle diagram, the following points should be noted. Although the theory assumes constant mutual flux, the diagram is drawn by means of the short-circuit and no-load points which are actual test



B.H.P.

FIG. 7.

data and are taken with constant terminal applied pressure; hence the results must agree at these two points, and the error at intermediate points is consequently smaller than would be the case if the circle diagram had been actually calculated under the assumption of constant mutual flux. Further, although the theory assumes that the I^2R loss due to the magnetising current is negligibly small, this loss is not actually entirely neglected in drawing the diagram, for it is included in the no-load and short-circuit measurements, and the error is again smaller than would be the case if the diagram were calculated under the assumption of negligibly small magnetising current.

The iron loss may reasonably be taken as approximately constant, since decrease of the rotor speed means decrease of mutual flux and decrease of stator iron loss, but increase of rotor iron loss.

Discussion.

Mr. Carr.

Mr. L. H. A. Carr: I should like to point out that Fig. 6 is practically the same as the standard approximate diagram given by Arnold and others, except that Arnold has carried the construction further and obtained a slip line in a more convenient position, *i.e.*, with the scale nearer the circumference of the circle at the working value of the current. To obtain Fig. 5 the author has made three assumptions, viz.: (1) Stator flux constant (negligible stator resistance); (2) iron losses constant; (3) I^2R loss due to magnetising component of current negligible. While the second of these is approximately true, the other two assumptions are not justified in practice if it is desired to obtain a true diagram of the performance of the machine, particularly if it is a

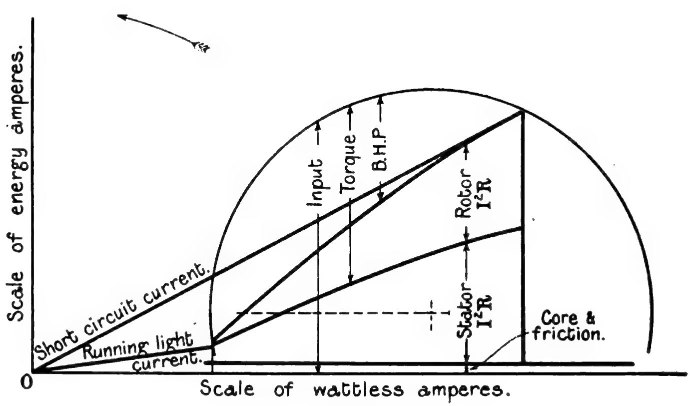


Fig. A.

small machine and has large (comparative) losses, or has many poles and hence high magnetising current. It is preferable to consider not the iron losses as constant, but the iron and friction losses, for then when the circle is constructed the friction torque at standstill is not indicated as useful torque on the diagram (as in the author's figure). When stator resistance is taken into account the centre of the circle becomes shifted upwards away from the x-axis. This can be shown by drawing a circle for constant back E.M.F. (constant flux) and then adding a portion $I r$ for the stator resistance to obtain the total terminal volts. The current vector can then be reduced in the proportion of the two voltages and turned through the necessary angle to reduce it to constant terminal voltage. If this is done for a series of points on the circle, the new constant-voltage circle will be seen to be raised above the old constant-flux circle. This has been shown more fully and proved by Arnold and La Cour. Their practical rule for finding the centre is, for stator and rotor equivalent resistances nearly equal, to erect a perpendicular on the "running light" point and to bisect the

intercept between this point and the short-circuit current line. The centre would lie on an abscissa through this bisection point. Test results over a wide range of motors down to fan motors of fractional horse-power show close agreement with the circle obtained by this method. Not only because of the "running light" I^2R loss, but also since the horizontal diameter does not pass through the "running light" point, the "straight line" method of obtaining the B.H.P. and torque lines does not give correct results, but the true lines of stator and rotor copper loss have to be calculated. This is quite easy, as the short-circuit losses being split up by marking off the stator copper losses (which are capable of fairly accurate determination) it is a simple slide-rule calculation to obtain the scale distance representing the loss proportional to the square of any given current line on the diagram. Fig. A shows from an actual test the shape these lines would assume. Consideration will show that in the case the author has dealt with, the facts that there was not a wide divergence between the no-load and short-circuit power factors, and that the magnetising was relatively small, tended to bring the centre of the true circle comparatively close to the author's approximations—and hence the agreement with his test results. However, to be of any practical utility the circle diagram must be constructed so as to represent correctly the case of every motor. A theory cannot be assumed to be proved because figures obtained by its use agree with practice in one particular case. Mr. Carr.

Dr. S. P. SMITH: Whilst the author is to be congratulated on his novel suggestion for developing the circle diagram for the induction motor by means of the rotating field, I have unfortunately not been able to follow the argument in his convention for the representation of the vector of this field. Thus on page 499 it is stated, "The vector of the rotating field will be drawn to coincide with the E.M.F. which it induces." But how could this be possible when the induced E.M.F. depends on the rate of variation of the field? Again, on page 501 it was stated that "the rotor current must be in phase with the actually existing rotor flux cutting the rotor winding." Surely this statement is liable to misinterpretation, for the rotor current is practically in phase with the induced pressure under normal conditions, whilst the pressure naturally lags 90° behind the flux inducing it. Similarly in Fig. 1, unless this is intended to represent M.M.F.'s, it should be regarded as a fictitious flux diagram except at no load, when the conditions for the stator would be somewhat as shown. Of course, if the fictitious flux diagram for the stator is added to a corresponding fictitious flux diagram for the rotor the actual flux diagram for the machine will be obtained as the resultant. The diagram deduced by the author differs very little from that developed by Ossana and used largely by Arnold as the no-load and short-circuit diagram. The use of circle diagrams for induction motors should not be over-estimated. Owing to the magnitude of pulsation losses and other uncertain quantities the simple Heyland diagram is sufficiently accurate for small motors. For larger motors above 50 H.P. a more accurate form might well be adopted, and close agreement Dr. Smith.

Dr. Smith. between test results and calculation could be expected. In such diagrams it was of the highest importance that the scales should be made quite clear both in the description and the application.

Mr. Shearing. Mr. G. SHEARING (*communicated*): The vector diagram given by the author differs considerably from those of other writers on the same subject. He has utilised the vector of a rotating field, as represented by the flux cutting the conductors of one phase, to deduce the diagram. This gives a phase displacement of 90° with respect to time for the rotating field and the current producing the field. It is due to this representation of the rotating field that the rotor current and the actually existing rotor flux are in phase with respect to time; that they are in phase is hardly clear from the paper. The following considerations may help to explain this. The actually existing rotor flux may be regarded as due to the vector combination of part of the stator rotating field and the rotor rotating field. The stator rotating field induces an E.M.F. in the rotor in phase. The rotor current lags with respect to this E.M.F. and sets up the rotor rotating field which lags with respect to the rotor current by 90°. Combining these hypothetical stator and rotor rotating fields we get the actual rotor field. The maximum value of this flux will be cutting a given rotor conductor at practically the same instant as that for which the current in that conductor is a maximum. Thus according to the author's convention they are in phase. The vector diagram is purely a time diagram in its phase relations. The circle diagram is obtained in a simple manner, and the above application of the rotating field vector seems to be new.

Dr. Coales. Dr. J. D. COALES: I have read Mr. Wall's paper with much interest, as the method there given for working out the various properties of the induction motor is simpler than, and preferable to, the more usual method in which two other circles are used for that purpose. As, however, he does not definitely show that the extremity of the current vector still moves on a circle, even when the stator has appreciable resistance and leakage, it may be of interest to show how this may be done by deducing the circle diagram from the well-known diagram of a transformer on short circuit. Fig. B is the diagram referred to. O M represents the induced E.M.F. in the secondary on short circuit; O N is the ohmic drop component; N M the leakage E.M.F. component; O A the magnetising current; O E the back E.M.F. in the primary (assuming a 1/1 ratio); E F and F V the ohmic and leakage E.M.F.'s in the primary excluding the corresponding negligibly small components produced by the magnetising current. Finally O V is the potential difference applied to the terminals of the primary. This diagram obviously also represents the conditions of each phase of an induction motor at standstill, and it is required to deduce from it the diagram for the running condition. First suppose that by suitably varying the applied potential difference the back E.M.F. and working flux are kept constant at all loads. Then as the rotor runs up from slip $= 1$ to the smaller slip s the rotor E.M.F. changes from O M to $s \times$ O M $=$ O M′ and O N′ M′ represents

the new E.M.F. triangle of the rotor. Produce M′ N′ to cut the perpendicular O L in L. Then N′ L O and N′ O M′ both represent ϕ_2, the new angle of lag in the rotor. Dr. Coales.

$$\text{Tan } \phi_2 = 2\pi f L_2 s / R_2 = \text{O M}'/\text{O L} = s \, . \, e/\text{O L},$$

where e is the induced E.M.F. in the rotor at standstill. From this it is seen that O L is a line of constant length, and since the angle at N′ is a right angle the locus of N′ is a semicircle. O N′ is equal to $R_2 I_2$, and represents the rotor current to scale. At A draw A D parallel and proportional to O N′, and to the same scale as the magnetising current O A; then the locus of D is a semicircle and D is the extremity of the stator current vector O D. Draw A C parallel to O N, then O C is the vector representing the stator short-circuit current. The vectors such as A D represent the components of the stator current which carry the load on the motor, and, neglecting the magnetising current for the present, may be taken to represent the full stator currents. To show that the locus of the extremity D is still a circle when the stator potential difference is kept constant, and in spite of stator resistance and leakage it is first necessary to find the locus of the extremity of the applied potential difference when the back E.M.F. O E is constant. In Fig. B, O V is the applied potential difference, and E F V the impedance triangle of the stator at standstill, E F being the ohmic drop and E V the impedance volts, which are proportional to the stator current, because the stator frequency is constant., E F is parallel and proportional to O N, and therefore, when the rotor runs up to speed, F moves round the circle G F E, while N moves round the circle L N O; and since the triangle E F V is of constant shape, with the angle E V F constant and the side E V proportional to stator current V moves round the circle E V′ V. Thus the locus of the extremity of the applied potential difference O V is a circle, when the back E.M.F. O E is constant. In Fig. C, which is the upper portion of Fig. B reproduced, E V′ represents the stator impedance volts, and therefore also the stator current under a condition of running, O V′ the applied potential difference, and O E the back E.M.F. Produce O E to O′ and draw a tangent to the circle at O′, namely O′ Y. Let O V′ or O V′ produced cut the circle again at W. The angle of lag of the stator current behind the back E.M.F. O E is F′ E O′ (E F′ being ohmic

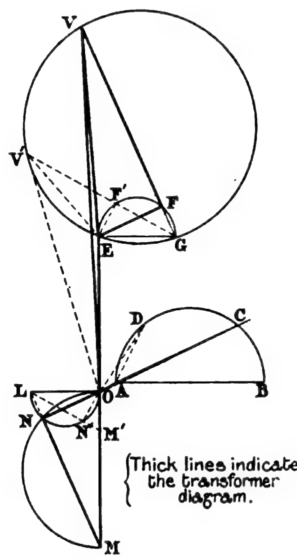


FIG. B.

Dr. Coales. drop) = E O′ V′ = E W V′. The angle of lag ϕ, of the stator current behind the applied potential difference, O V′ is equal to the sum of the angles E W V′ + E O V′ = W E O′, and W E O′ = W O′ Y. Further, suppose the applied potential difference is in every case increased to the constant value O O′, then all the lines of the diagram will be increased

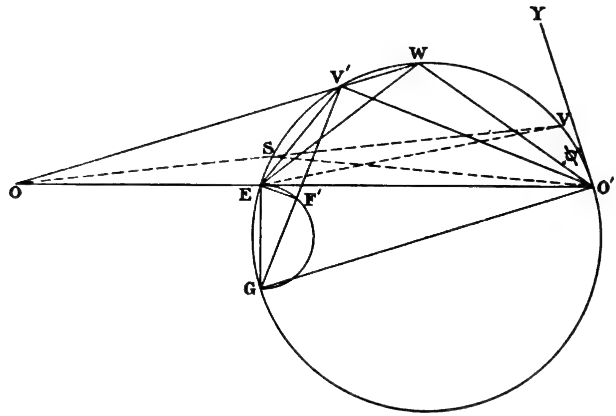


FIG. C.

in the same ratio without altering the phase relations. And this ratio will be O O′/O V′. Consider the triangles O E V′ and O W O′. These triangles are equiangular, and O′ W/E V′ = O O′/O V′, and therefore O′ W represents to scale the value of the stator current when the applied potential difference is increased in the ratio O O′/O V′. It has been shown that the angle W O′ Y is the angle of lag of the stator

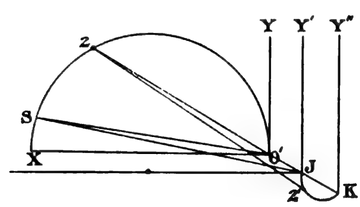


FIG. D.

current behind the applied potential difference. Thus if O′ Y represents the phase of the applied potential difference, then vectors such as O′ W represent the stator currents in phase and magnitude, when the applied potential difference is represented to scale by O O′, and the locus of the extremities of the stator currents is therefore the circle O′ W E. By the same construction O′ S now represents the short-circuit current, and Y O′ S its angle of lag; O S the back E.M.F. on short

circuit. O W represents the back E.M.F. with the stator current O′ W. Dr. Coales. In order to construct the diagram with allowance for the magnetising current, proceed as in Fig. D, remembering that the magnetising current at short circuit is, roughly, half the magnetising current at no load, because it is proportional to the back E.M.F., and also that its extremity will describe a small circular arc between its extreme values similar to the arc E W O′ (Fig. C). In Fig. D let K Y″ represent the position of the applied potential difference. Set off K O′ to represent the no-load magnetising current to scale at the appropriate angle of lag Y″ K O′. Bisect K O′ in J. At J set off J S to represent the short-circuit current to scale at its angle of lag Y′ J S. Join O′ S, then O′S represents the current vector O′ S in Fig. C. Describe the circle through O′ and S with its centre on the line O′ X perpendicular to O′ Y. On J K describe an arc J 2′ K similar to S 2 O′. Then we have O′ K representing magnetising current, J S representing short-circuit current, and 2 2′ representing the true stator current corresponding to a vector such as O′2, where 2′ is a point on the arc, J 2′ K having an arc distance J 2′ corresponding in proportion with the arc distance S 2. It is generally sufficient to take the magnetising current as being equal to the no-load current, but for greater accuracy it may be obtained from the no-load current by correcting it for the friction losses. The friction losses are obtained most easily from the following consideration: Slip S_1 at no load is proportional to torque T_f due to friction. Apply a small mechanical torque T. Then the new slip S_2 is proportional to $T + T_f$; therefore $S_2/S_1 = (T + T_f)/T_f$, from which T_f is calculated. The loss due to friction at no load is then $2 \pi n_1 T_f$, where n_1 is the speed at slip S_1. From this the current per phase due to friction can be calculated and subtracted vectorially from the no-load current to obtain the magnetising current.

Mr. T. F. WALL (*in reply*): With reference to the remarks of Mr. Mr. Wall. L. H. A. Carr as to the assumptions made in deducing the diagram, I would call attention to the last two paragraphs of the paper. It is stated there that the error due to the assumptions made is less than would appear at first sight, owing to the fact that the circle diagram is drawn through the two actual test-points. As an old student of the late Professor E. Arnold, I fully appreciate the methods employed by him and his collaborators in developing the circle diagram for the induction motor. At the same time, it cannot be denied that Professor Arnold's methods are not easily understood. So far as the circle is concerned, there are two points which must be the same for both methods, viz., the experimentally obtained no-load and short-circuit points, the difference lying in a slight relative displacement of the centre of the circle. The motor referred to in the paper was an 8-B.H.P., 6-pole machine, and was used because it was the first available for the test. Professor Arnold's approximate construction referred to by Mr. Carr would be found to give a circle practically coincident with that of Fig. 6 of the paper. There is, however, another point which should be noticed, and that is the influence of saturation of the magnetic

Mr. Wall. circuit. Professor Arnold assumed that the iron had constant permeability, and modern motors are certainly not worked below the saturation-point. It was then hardly logical to insist on extreme accuracy in one direction if there may be, comparatively speaking, considerable error in another. If Mr. Carr is not satisfied that the test figures given are sufficient evidence of the accuracy of the circle diagram, I would like to see curves deduced similar to that of Fig. 7, and thus ascertain what discrepancy might be expected in those cases which Mr. Carr considers to be doubtful. Referring to Dr. Smith's remarks, it is surprising that the statement contained in his first quotation is not obvious. If a conductor is cut by a steady and uniformly rotating field, the E.M.F. induced in that conductor is at every instant proportional to the field cutting the conductor at that instant. The reason why I chose the E.M.F. to represent the flux vector, instead of dealing with the field itself, is because the E.M.F. induced by the rotating field takes the direction of rotation of the field into account. This method of representing the rotating field seems to me to be a perfectly natural one. A full appreciation of these points should clear away the difficulty found in understanding the second quotation. The reference to Fig. 1 seems to show that Dr. Smith is not very familiar with the superposition method of dealing with magnetic problems. Fig. 1 shows diagrammatically the rotating field which would be established by a 3-phase current in the stator winding, if the rotor winding were carrying no current. With regard to the scales of the diagram, it should be noted that in Fig. 5 $B_1 U$ represents the watt component of the current per phase corresponding to the developed horse-power, *i.e.*, the applied volts per phase $\times$ current $B_1 U \times$ No. of phases $\div$ 746 gives the horse-power which $B_1 U$ represents. Again $B_1 W$ represents the watt component of the current per phase corresponding to the power transferred to the rotor, *i.e.*, the applied volts per phase $\times$ current $B_1 W \times$ No. of phases $=$ torque $\times$ synchronous speed in radians per second. The torque obtained from this relation is represented by the line $B_1 W$. I have been much interested in the proof given by Dr. Coales that the current diagram is still a circle, for the case in which the stator applied pressure is maintained constant, and only the pressure drop due to the magnetising current is neglected. If Dr. Coales would carry the proof a step further, and show that the current diagram is also a circle when the pressure drop due to the magnetising current is taken into account, and the point 2′ in Fig. D becomes a fixed point, it would add still further to the value of this solution.

DYNAMOMETER AMPEREMETERS AND VOLTMETERS.

By J. L. D. RIDSDALE, Student.

(*Received 30th October, 1911, and received in final form 16th January, 1912.*)

Although the theory of the dynamometer wattmeter has been very fully investigated, very little attention appears to have been paid to the question of the dynamometer amperemeter and voltmeter. This is no doubt largely due to the fact that it is generally considered to be a comparatively easy matter to design an accurate instrument for the measurement of current or voltage. Yet in the case of an amperemeter, at any rate, there are certain points which need very careful attention, if it is desired to produce an instrument that shall be accurate under all conditions met with in practice.

It may be stated at the outset that the two great difficulties that confront the designer are the elimination of frequency and temperature errors: and in this paper it is proposed to show how the errors due to these factors can be reduced to a negligible amount.

1. DYNAMOMETER AMPEREMETERS.

The simplest and most accurate form of amperemeter is that in which the fixed and moving coils are placed in series, and the whole current taken through both. There is then no temperature error, and providing eddy currents are absent, the instrument will be equally accurate whether used on continuous-current or alternating-current circuits.

Such a method of connecting up the coils is employed in the well-known Siemens dynamometer, so largely used as a sub-standard. But for ordinary deflexional instruments this simple series connection cannot be used with currents above, say, 1 ampere, owing to the limitations set by the springs leading the current in and out of the moving coil.

It therefore becomes necessary to consider what are the possible means of increasing the range of the instrument. The most obvious method of doing this is to "shunt" the instrument, as shown in the diagram (Fig. 1). In such a case, of course, a certain amount of non-inductive resistance would be placed in series with the coils for the purpose of reducing the temperature and frequency errors. It is, how-

ever, difficult to render these negligible, and in any case such a method entails a considerable "drop" over the shunt, which means that for heavy currents the shunts will be large and expensive. The use of shunts, however, has one advantage in that only one instrument is required for any number of ranges.

In order to bring out the above points more clearly, it will be well to consider a specific example. Take the case of an instrument, which normally gives full-scale deflexion with 1 ampere through its fixed and moving coils, and suppose it is desired to increase its range to 100 amperes.

In a particular instrument the fixed coil was wound with 100 turns of wire, resistance 0·15 ohm, and the moving coil with 30 turns, the resistance of which, with the springs, was 0·18 ohm. Hence the total resistance of the two coils in series is 0·33 ohm. If now it is desired to use this instrument with a shunt, it will be necessary to include in series with the coils some non-inductive resistance having a negligible

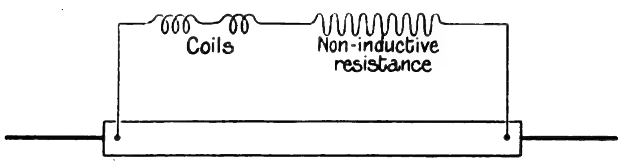


FIG. 1.

temperature coefficient. The total resistance can conveniently be made 1 ohm. There will then be required 1 volt drop across the shunt.

Since the copper is $\frac{1}{3}$ of the total resistance, the temperature error will be 0·14 per cent. per ° C. rise.

In order to determine the frequency error, we require to know the time constant of the instrument. The self-induction of the fixed coil is 0·25 millihenry, and of the moving coil 0·026 millihenry, giving a total inductance of 0·276 millihenry. The total resistance of the instrument, apart from the shunt, is 1 ohm, and hence the time constant is $\frac{2{\cdot}76}{10^4}$ seconds. Assuming for the moment that the shunt is non-inductive, its time constant will be zero. Let M be the multiplying power of the shunt for continuous currents and M′ for alternating currents, then as has been shown by Dr. C. V. Drysdale *—

$$M' = M\sqrt{1 + \left(\frac{M-1}{M}\right)^2 T^2 p^2},$$

where T is the time constant of the instrument and p is 6·28 × frequency, as usual.

* *Philosophical Magazine*, vol. 16, p. 138, 1908

In the case under consideration—

$$T = \frac{2{\cdot}76}{10^4} \text{ seconds, and } \quad M = 100\,;$$

hence on a 50-frequency circuit $M' = 1{\cdot}0037\,M$, that is, the instrument will read 0·37 per cent. low if calibrated on a continuous-current circuit. In the same way on a 100-frequency circuit the error will be nearly 1½ per cent. This example clearly shows that shunting an amperemeter in this way may introduce considerable frequency and temperature errors, far beyond what would be permissible in a laboratory standard instrument. The only remedy—other than using an excessive volt drop—is to make the time constant of the shunt equal to that of the instrument. This is, however, difficult to carry out in practice.

If, however, the connections, as shown in Fig. 1, are slightly modified, the moving coil only being shunted, and the fixed coil

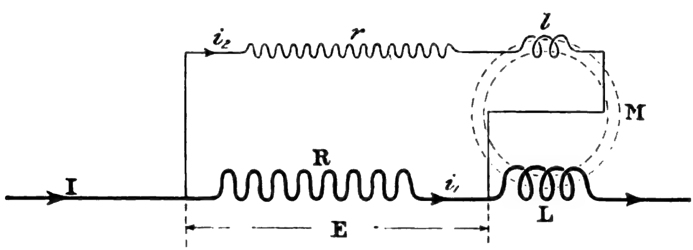


FIG. 2.

carrying the whole of the current, it is possible to produce an amperemeter which will read with equal accuracy whether used on continuous- or alternating-current circuits.

This method of connecting the coils is shown diagrammatically in Fig. 2.

In order to find the effects of frequency and wave-form on an instrument connected up in accordance with the above diagram, we proceed in the following way :—

Let—

E = "drop" over the shunt, which will be assumed to have negligible self-induction.

R = the resistance of the shunt, and r the total resistance of the moving coil circuit.

l = the self-induction of the moving coil, and M = the coefficient of mutual induction between the fixed and moving coils.

Adopting the Steinmetz notation we have—

$$E = i_2(r + jpl) + jpMI,$$

where i_2 is the current through the moving coil, I the main current, and $p = 6{\cdot}28 \times$ frequency, whence—

$$i_2 = \frac{E - jpMI}{r + jpl}.$$

The current through the shunt is given by—

$$i_1 = \frac{E}{R}.$$

Hence—

$$i_1 + i_2 = I = \frac{E}{R} + \frac{E - jpMI}{r + jpl};$$

from which we derive—

$$E = I \cdot \frac{r + jpl + jpM}{R + r + jpl} R,$$

but—

$$i_2 = \frac{E - jpMI}{r + jpl}.$$

Substituting for E we have—

$$i_2 = \frac{I}{r + jpl}\left[\frac{(r + jpl + jpM)R}{R + r + jpl} - jpM\right]$$

which reduces to—

$$i_2 = I \cdot \frac{R - jpM}{R + r + jpl}$$

rationalising—

$$i_2 = I\frac{R(R+r) - pMpl - j[pM(R+r) + plR]}{(R+r)^2 + p^2 l^2}.$$

Hence if A is the angle between I and i_2—

$$\tan A = \frac{pM(R+r) + plR}{R(R+r) - pMpl}.$$

$$\therefore \quad \cos A = \frac{R(R+r) - pMpl}{\sqrt{(R^2 + p^2M^2)(R + r^2 + p^2l^2)}}$$

Multiplying the expression for i_2 by I we have—

$$I i_2 = I^2 \frac{R(R+r) - pMpl - j[pM(R+r) + plR]}{(R+r)^2 + p^2l^2}$$

Converting to "real" form, after some reduction we get—

$$I i_2 = I^2 \sqrt{\frac{R^2 + p^2M^2}{(R+r)^2 + p^2l^2}}.$$

Hence—

$$I\, i_2 \cos A = I^2 \frac{R\,(R+r) - p\,M\,p\,l}{(R+r)^2 + p^2\,l^2}$$

$$= I^2 \frac{R}{R+r} \left[\frac{1 - p\left(\frac{M}{R}\right) p \left(\frac{l}{R+r}\right)}{1 + p^2 \left(\frac{l}{R+r}\right)^2} \right]$$

Let—

$$\frac{l}{R+r} = T,$$

then—

$$I\, i_2 \cos A = I^2 . \frac{R}{R+r} \left[\frac{1 - p\,M/R\,.\,p\,T}{1 + p^2\,T^2} \right]$$

Now R, the resistance of the shunt, will only be a small fraction of r, say 5 per cent. even for currents as low as 5 amperes.

Hence we may say, without serious error, that T is the time constant of the moving coil circuit.

With regard to the mutual induction, it is to be noticed that this varies with the angular position of the moving coil: at the middle of the scale, where the coils are at right angles, M will vanish, and at either end of the scale M will have a maximum value. It is this value of M that must be used in determining the frequency error.

When used with continuous current the torque is proportional to the product of the shunt coil current, and the field in which it moves, or more correctly the component of this field parallel to the plane of the coil. If we neglect the disturbing effect of the shunt coil field, which will in any case be very small, and moreover vary with the position of the coil, the field in which the moving coil swings is proportional to I, the main current. The shunt coil current is equal to $\frac{R}{R+r}$ I. Hence the torque when used with continuous current is given by—

$$T_q \equiv k_1\, I^2 \frac{R}{R+r},$$

where k_1 depends on the angular position of the moving coil.

Again, with the same assumptions as before, and in addition assuming the absence of eddy currents, the torque when used with alternating current is given by—

$$T_q \equiv k_1\, I\, i_2 \cos A$$

$$\equiv k_1\, I^2 \frac{R}{R+r} \left[\frac{1 - p\,M/R\,.\,p\,T}{1 + p^2\,T^2} \right]$$

Let I′ be the alternating current which produces the same torque as a continuous-current I, then we have—

$$I' = I \sqrt{\frac{1 + p^2\,T^2}{1 - p\,M/R\,p\,T}}.$$

This equation can be written in the form—

$$I' = I\,(1 + \tfrac{1}{2}p^2T^2)\,(1 + \tfrac{1}{2}p\,M\;R\,.\,p\,T),$$

or—

$$I' = I\,[1 + \tfrac{1}{2}p\,T\,(p\,.\,M/R + p\,T)].$$

Hence if the instrument is calibrated with continuous current, the percentage error when used with alternating current will be—

$$100\frac{p\,T}{2}\,(p\,M/R + p\,T).$$

The coefficient M can be expressed in terms of L, the self-induction of the fixed coil.

The E.M.F. of self-induction in the fixed coil is $p\,L\,I$. If now all the flux of the fixed coil were interlinked with the moving coil, the E.M.F. induced therein would be—

$$p\,L\,I\,\frac{n_2}{n_1},$$

where n_1 and n_2 are the turns on the fixed and moving coils respectively.

As a matter of fact, however, only a small part of the flux of the fixed coil is interlinked with the moving coil, and hence we may say that the E.M.F. actually induced therein is—

$$k\,.\,p\,L\,I\,\frac{n_2}{n_1},$$

where k varies with the position of the moving coil. Hence we have—

$$p\,M\,I = k\,p\,L\,I\,\frac{n_2}{n_1}$$

whence—

$$\frac{p\,M}{R} = k\,p\,\frac{L}{R}\,\frac{n_2}{n_1}$$

Now R, the resistance of the shunt, is very nearly equal to E/I, since only a very small fraction of the whole current passes through the moving coil. Substituting this value for R in the above equation, we get—

$$\frac{p\,M}{R} = k\,\frac{L\,I}{n_1}\,p\,.\,\frac{n_2}{E}.$$

But—

$$\frac{L\,I}{n_1} = F \times 10^{-8},$$

where F is the total flux of the fixed coil.

Hence we have finally—

$$\frac{p\,M}{R} = k\,F_1\,p\,.\,\frac{n_2}{E}\,10^{-8}.$$

For any particular line of instruments, all the factors contained in the expression on the right-hand side of the last equation should be constant whatever the value of the current I. For it should always be endeavoured to work with the same ampere-turns on the fixed coil and the same shunt drop, which means that F, E, and n_2 would be the same in all cases. The value of k was determined, once and for all, by means of a ballistic galvanometer. It was found that with the planes of the fixed and moving coils inclined at 45°—this being the relative position of the coils at either end of the scale—the value of k was 0·165. It may be mentioned here that tests were also made to determine how much of the flux of the moving coil was interlinked with the turns of the fixed coil. It was found that even at the extreme ends of the scale this was such a small percentage as to be negligible. It may be said, therefore, that the moving coil produces only a self-inductive effect and has no influence on the mutual induction.

Returning now to the expression—

$$\text{Per cent. error} = 100\,\frac{p\,T}{2}\,(p\,M/R + p\,T)$$

we can substitute the known values of the various terms contained in the above expression and hence deduce the frequency error.

In a particular instrument it was found that $r = 4$ ohms, $l = 0·03$ millihenry, $n_2 = 32\frac{1}{2}$, F = 1,000 C.G.S. lines, and E = 1 volt. Hence—

$$T = \frac{l}{r} = \frac{3}{4}\,10^{-5}.$$

$$M/R = k\,F\,\frac{n_2}{E}\,10^{-8} = 165 \times 32·5 \times 10^{-8}$$

$$= 5·36\,10^{-5}.$$

Hence at a frequency of 100, per cent. error $= \frac{0·9}{100}$, say 0·01 per cent.

This result is entirely in accordance with the observed facts; for careful tests made on instruments having the same electrical data as given above failed to show any appreciable error due to varying frequency.

Up to the present the existence of pure sine waves has been tacitly assumed, but the previous results can easily be extended to include the case of any wave-form.

We have seen that the torque due to a current whose virtual value is I, and which varies harmonically with time, is given by—

$$T_q \equiv I^2\,\frac{R}{R + r}\,\frac{1 - p\,T\,p\,M/R}{1 + p^2\,T^2},$$

which may be written—

$$T_q = c\,.\,I^2\,\frac{1 - p\,T\,.\,p\,M/R}{1 + p^2\,T^2}.$$

If now we consider the case of a current wave of any shape whatever, this being resolved into a fundamental wave, and a number of harmonics, each harmonic will produce its own component of the total torque, but, as is well known, the various harmonics will not combine to produce any torque one with another. The total torque will consequently be represented by a series of terms similar to the above expression, suitable values of I and p being introduced. The general term giving the torque due to the nth harmonic will be—

$$T_{qn} = c \, . \, I_n^2 \, \frac{1 - n\,p\,T \, . \, n\,p\,M/R}{1 + n^2\,p^2\,T^2}.$$

where I_n is the virtual value of the nth harmonic. In order to simplify the investigation of the effects of wave-form we shall consider the two extreme cases of a rectangular wave and a triangular wave. The instantaneous value of the former is given by the equation—

$$i = \frac{4}{\pi} \left(I_m \sin a + \tfrac{1}{3} I_m \sin 3\,a + \tfrac{1}{5} I_m \sin 5\,a + \ldots \right)$$

the nth harmonic will be

$$\frac{4}{\pi\,n} I_m \sin n\,a,$$

where I_m is the maximum value of the current wave. But for a rectangular wave the maximum value I_m is the same as the virtual value I: hence the nth harmonic becomes—

$$\frac{4}{\pi\,n} \; I \sin n\,a.$$

The maximum value of this harmonic is obviously $\frac{4}{\pi\,n} I$ and the virtual value $\frac{4}{\pi\,n} \frac{I}{\sqrt{2}}$.

i.e.—

$$I_n = 2 \, \frac{\sqrt{2}}{\pi\,n} \; I,$$

and—

$$I_n^2 = 0{\cdot}81 \, \frac{I^2}{n^2}$$

Hence for a rectangular wave the total torque is given by—

$$T_q = 0{\cdot}81 \, c \, I^2 \left[\left(\frac{1 - p\,T \, . \, p\,M/R}{1 + p^2\,T^2} \right) + \frac{1}{9} \left(\frac{1 - 9\,p\,T \, . \, p\,M/R}{1 + 9\,p^2\,T^2} \right) \right.$$

$$\left. + \frac{1}{25} \, . \left(\frac{1 - 25\,p\,T\,p\,M/R}{1 + 25\,p^2\,T^2} \right) + \ldots \right]$$

Hence as before—

$$I' = I \cdot \frac{1}{0{\cdot}9003\sqrt{\left(\frac{1}{1+p^2T^2}+\frac{1}{9}\cdot\frac{1}{1+9p^2T^2}+\ldots\right)-pT\,pM/R\left(\frac{1}{1+p^2T^2}+\frac{1}{1+9p^2T^2}+\ldots\right)}}$$

If we put $T=0$ and evaluate the expression under the square root sign, we have up to $n=21$—

$$I' = I\,\frac{1}{0{\cdot}99073},$$

which is within 1 per cent. of the final value.

Substituting the values of pT, and pM/R, and taking the fundamental frequency as 100 we get—

$$I' = I\,\frac{1}{0{\cdot}98993},$$

a result which differs from the last by only 8 parts in 10,000, *i.e.*, the error on a flat-topped wave will be rather less than $\frac{1}{10}$ of 1 per cent.

Taking next the case of the triangular wave, the instantaneous value is given by—

$$i = \frac{8}{\pi^2}\left(I_m \sin a - \frac{I_m}{9}\sin 3\,a + \frac{I_m}{25}\sin 5\,a\ldots\right)$$

the nth harmonic is—

$$\frac{8}{\pi^2}\,I_m\,(-1)^{\frac{n-1}{2}}\,\frac{\sin n\,a}{n^2},$$

I_m, as before, being the maximum value of the current wave. Remembering that the virtual value $I = I_m/\sqrt{3}$ it is easily seen that the virtual value of the nth harmonic is given by—

$$I_n = \frac{8}{\pi^2 n^2}\sqrt{\frac{3}{2}}\,I,$$

or—

$$I_n = 0{\cdot}9855\,\frac{I^2}{n^4},$$

whence the total torque for this case is given by—

$$T_q = 0{\cdot}9855\,c\,I^2\left[\left(\frac{1}{1+p^2T^2}+\frac{1}{3^4}\cdot\frac{1}{1+9p^2T^2}+\frac{1}{5^4}\cdot\frac{1}{1+25p^2T^2}+\ldots\right)\right.$$
$$\left.-pT\,.\,pM/R\left(\frac{1}{1+p^2T^2}+\frac{1}{9}\cdot\frac{1}{1+9\,.\,p^2T^2}+\frac{1}{25}\cdot\frac{1}{1+25p^2T^2}+\ldots\right)\right]$$

whence—

$$I' = I\,\frac{1}{0{\cdot}99277\sqrt{\left(\frac{1}{1+p^2T^2}+\frac{1}{3^4}\cdot\frac{1}{1+9p^2T^2}+\ldots\right)-pT.pM/R\left(\frac{1}{1+p^2T^2}+\frac{1}{9}\cdot\frac{1}{1+9p^2T^2}+\ldots\right)}}$$

If $T=0$ this reduces to—

$$I' = I \frac{1}{0{\cdot}99999}$$

neglecting terms beyond the 11th harmonic. On substituting the values of pT and pM/R, the equation becomes—

$$I' = I \frac{1}{0{\cdot}99990},$$

i.e., the error is about 1 part in 10,000.

It can be concluded, therefore, that the effect of wave-form is negligibly small, the greatest error being produced by a flat wave and the least by a peaked wave-form.

In the formula for the torque due to the nth harmonic—

$$T_{qn} = c\, I_n^2 \frac{1 - npT \,.\, npM/R}{1 + n^2 p^2 T^2}$$

it is to be noticed that if—

$$npT \,.\, npM/R = 1,$$

or inserting the value of $T = \frac{l}{R+r}$, if—

$$npM \,.\, npl = R(R+r),$$

the torque vanishes.

This is easily explained by reference to the formula for the tangent of the angle between the two current components of the torque. This has already been found to be—

$$\tan A = \frac{npM(R+r) + nplR}{R(R+r) - npM\,npl} \text{ for the } n\text{th harmonic.}$$

Hence if $R(R+r) = npM \,.\, npl$—

$$\tan A = \infty \quad \text{or} \quad A = 90^\circ.$$

If the value of np exceeds that determined by the above equation the torque is reversed in sign, *i.e.*, any very high harmonics will produce a negative torque.

We next consider briefly the temperature error.

At the temperature at which the instrument is calibrated the torque is given by—

$$T_q \equiv k_1 I^2 \frac{R}{R+r},$$

R, the resistance of the shunt, has no temperature coefficient, but r will have an equivalent coefficient a.

Hence for a rise of t° Cent. the torque is given by—

$$T_q' = k_1' I^2 \frac{R}{R + r(1 + a t)}.$$

A current I′ will be required to make $T_q' = T_q$, and obviously—

$$I' = I \sqrt{\frac{R + r(1 + a t)}{R + r}} = I \left(1 + \frac{1}{2} \cdot \frac{r}{R + r} a t\right).$$

As R is always very small compared to r, it will be sufficiently accurate to say that—

$$I' = I \left(1 + \tfrac{1}{2} a t\right),$$

i.e.—

$$\text{Per cent. error} = \tfrac{1}{2}\, 100\, a\, t.$$

The virtual temperature coefficient of the moving coil circuit is given by—

$$a = \frac{r_1 a_1 + r_2 a_2}{r_1 + r_2 + r_3},$$

where—

r_1 = resistance of moving coil.
r_2 = resistance of springs.
r_3 = non-inductive resistance.
a_1 = temperature coefficient of moving coil.
a_2 = temperature coefficient of springs.

It is well known that a will be a minimum when—

$$\frac{r_1}{r_2} = \frac{a_2}{a_1}.$$

In an actual case—

$r_1 = 0{\cdot}18$ ohm.
$r_2 = 0{\cdot}32$ „
$r_3 = 3{\cdot}5$ ohms.

The temperature coefficient of low-resistance silicon-bronze springs, such as would be used for an amperemeter of this description, is 0·002, or about half that of copper, which we may take as 0·004.

Inserting these values—

$$a = 0{\cdot}00034.$$

Hence for a rise in temperature of 10° C. the error will be about $\frac{1}{6}$ of 1 per cent.

It is evident, therefore, that a dynamometer amperemeter constructed on the lines indicated, can be rendered almost entirely free from frequency errors and tolerably free from temperature errors, with a "drop" over the shunt not exceeding 1 volt.

2. Dynamometer Voltmeters.

The design of an accurate dynamometer voltmeter is a much simpler matter than the case of an amperemeter. In fact, if a relatively large power consumption is no objection, the problem presents no very great difficulties.

In the voltmeter, the moving and fixed coils are almost universally joined in series, together with a sufficient amount of non-inductive resistance to render the frequency and temperature errors negligible.

If R is the total resistance, L the sum of the self-induction of the fixed and moving coils, and M the mutual induction, then—

$$E = i(R + jpL + jpM),$$

where E is the applied voltage and i the current passing through the coils.

Since the torque will be proportional to i^2 under the same assumptions as before, we at once find the ratio of the voltages required to produce the same torque on alternating current as on continuous current to be—

$$\sqrt{\frac{R^2 + p^2(L + M)^2}{R^2}}$$

which—

$$= 1 + \tfrac{1}{2} p^2 T^2 \text{ very nearly,}$$

where—

$$T = \frac{L + M}{R}, \text{ the time-constant of the instrument.}$$

Take the case of a 150-volt instrument.

The fixed coil is wound with 2,000 turns and has a self-induction of 100 millihenries, and the moving coil with 300 turns self-induction 2·6 millihenries. It has already been shown that—

$$M = k L \frac{n_2}{n_1},$$

the value of k being $= 0·165$.

Substituting we have—

$$M = 2·32 \text{ millihenries.}$$

Hence—

$$L + M = 104·92 \text{ millihenries} = 0·105 \text{ henry (say).}$$

The total resistance of the instrument is 2,000 ohms. Hence—

$$T = \frac{0·105}{2000} = \frac{5·25}{10^5}.$$

Hence at a frequency of 100 the percentage error—

$$= \tfrac{1}{2}\, 100\, p^2 T^2$$
$$= \tfrac{1}{20} \text{ of 1 per cent. approximately.}$$

It is seen from the foregoing example that the mutual induction in voltmeters produces very much less effect than in amperemeters. The

question of temperature error is so simple that it need not be considered here.

Up to the present we have considered only in detail the question of indicating instruments, in which the working forces required are comparatively small. In the case of recording instruments, however, where the pen records directly on the chart—as distinct from the "tapper" type—much larger working forces are necessary in order that pen friction may not affect the accuracy of the instrument.

Where dynamometer recording amperemeters are employed on alternating-current circuits it is the universal practice to use current transformers with a 5-ampere instrument. The design of an instrument for this current on the same lines as adopted for indicating instruments (see Fig. 2) is a matter of no great difficulty. It is a fairly easy matter to produce an instrument which will have ample control,

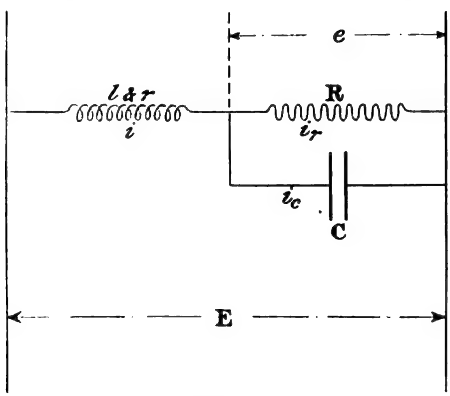


FIG. 3.

and which at the same time will be correct on all frequencies to within some ½ per cent., a degree of accuracy which is generally sufficient for recorders. It may be objected that such an instrument is not "universal," in that it cannot be used on continuous-current circuits. In answer to this objection, however, it may be stated that a recording amperemeter for use both on continuous- and alternating-current circuits is very seldom called for.

The case of recording voltmeters, however, is different, for such an instrument is very frequently required both for continuous-current and alternating-current circuits. Hence it is necessary to look into the question of accuracy somewhat more in detail.

Owing to the fact that large working forces are essential, it is impossible to reduce the time constant of the instrument to a negligible value. This means that there will be appreciable frequency errors unless steps be taken to minimise the effects of self-induction. In practice this is effected by the use of a condenser either in parallel

with the coils of the instrument, or in parallel with the non-inductive resistance.

Consider first the case in which the condenser is placed in parallel with the non-inductive resistance.

In the diagram Fig. 3, C represents the condenser, R the non-inductive resistance, and l and r the self-induction and resistance of the coils. We shall neglect any effect due to mutual induction, as this will be very small owing to the fact that in a recorder the coils are never more than some 15° out of the right-angle position.

The total impedance of the recorder is obviously given by—

$$Z = r + j p l + \frac{1}{\frac{1}{R} + j p C}.$$

Putting this into real form, we get after some reduction—

$$Z^2 = r^2 + p^2 l^2 + \frac{R^2 + 2 R r - 2 p^2 R^2 l C}{1 + p^2 C^2 R^2}.$$

If the instrument is to read correctly on alternating-current and on continuous-current circuits, the impedance Z must be numerically equal to $(R + r)$, *i.e.*—

$$p^2 l^2 - 2 R r - R^2 + \frac{R^2 + 2 R r - 2 p^2 R^2 l C}{1 + p^2 C^2 R^2} \text{ must} = 0.$$

This equation may be written—

$$C^2 - C \frac{2 l}{p^2 l^2 - 2 R r - R^2} + \frac{l^2}{R^2 (p^2 l^2 - 2 R r - R^2)} = 0.$$

Solving for C we have—

$$C = \frac{l}{p^2 l^2 - 2 R r - R^2} \left(1 \pm \sqrt{1 - \frac{p^2 l^2 - 2 R r - R^2}{R^2}}\right).$$

This may be written in the form—

$$C = \frac{l}{R_t^2 - Z_c^2} \left(\pm \sqrt{1 + \frac{R_t^2 - Z_c^2}{R^2}} - 1\right) \text{ farads,}$$

where R_t = total resistance of instrument, and Z_c = the impedance of the coils only.

For all ordinary frequencies R_t will be greater than Z_c, and hence C will have one positive value and one negative value. The latter value of C is of theoretical interest only; its meaning is easily arrived at. For if in Fig. 3 the condenser C were replaced by a choking coil L, having no resistance, the total impedance would again be given by

the formula already found, by substituting $-1/p\,L$ for $p\,C$. The negative value of C, then, is equivalent to a self-induction L, whose value is given by $\frac{1}{p^2\,C}$. It need hardly be pointed out that "compensating" a recorder by placing a choking coil in parallel with the non-inductive resistance is not a method that could be employed in practice. For on continuous-current circuits the choking coil would, of course, short circuit the resistance R. In an actual recorder wound for a 220-volt circuit, the constants were as follows: $l = 0{\cdot}88$ henry, $R = 2{,}200$ ohms, and $r = 480$ ohms. Inserting these values in the above formula for C we get—

For a frequency of	100, $C = 0{\cdot}0716$	microfarad.
" "	50, $C = 0{\cdot}071$	"
" "	25, $C = 0{\cdot}071$	"

We see therefore that the same value of C will, for all practical purposes, compensate for the self-induction of the coils whatever the frequency. It may be stated that, on test, a capacity of 0·075 microfarad was required to eliminate frequency errors.

For a 110-volt recorder the constants were: $l = 0{\cdot}22$ henry, $R = 600$ ohms, and $r = 100$ ohms. Inserting these values in the formula, the values of C for frequencies varying from 25 to 100 are—

For a frequency of	100, $C = 0{\cdot}244$	microfarad.
" "	50, $C = 0{\cdot}242$	"
" "	25, $C = 0{\cdot}2418$	"

Incidentally these results verify a point which is amply borne out in practice, namely, that the lower the voltage the more difficult it is to compensate. In fact, for voltages below 100 it is practically impossible to render a recorder free from frequency errors.

It will be interesting to draw a vector diagram for the case of the 220-volt instrument cited above. It will then be seen at once how a condenser or choking coil in parallel with the non-inductive resistance will compensate for the self-induction of the coils. The current through the coils of the instrument, when "compensated," having the same value on continuous- and alternating-current circuits, is equal to $\frac{220}{2{,}200 + 480}$ amperes—*i.e.*, is equal to 0·0821 ampere.

The voltage across the condenser is given by—

$$e = \frac{i\,R}{\sqrt{1 + p^2\,C^2\,R^2}},$$

i being the total current—*i.e.*, $i = 0{\cdot}0821$ ampere.

The value of C as found is 0·0716 microfarad and $-0{\cdot}337$ micro-

farad, $R = 2{,}200$ ohms. Inserting these values we get $e = 179{\cdot}5$ volts and $163{\cdot}8$ volts, taking the frequency as 100.

The magnitude and direction of the current through the resistance R can now be obtained. This fixes the magnitude and direction of the vector representing the voltage e.

The drop over the coils of the instrument is equal to $i\sqrt{r^2 + p^2 l^2}$. Inserting the values of r and l, and remembering that $i = 0{\cdot}0821$ ampere, we find this "drop" to be 60 volts on a 100-frequency circuit, and it will lead the current by an angle ϕ, such that $\tan\phi = p\,l/r$, which

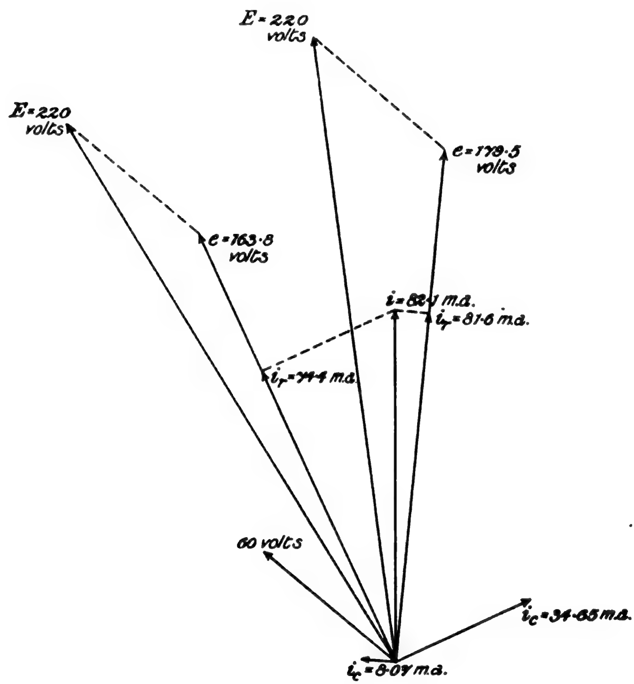


FIG. 4.

gives $\phi = 49°$. The vector sum of this voltage and the "drop" over the resistance R is equal to the voltage applied to the terminals of the instrument, which on reference to the diagram Fig. 4 will be seen to be equal to 220 volts for both the values of C given above.

Consider next the case of the condenser in parallel with the coils of the instrument. This arrangement is shown diagrammatically in Fig. 5.

We require to find the current i passing through the coils in terms of the applied voltage E.

The combined impedance of l and r in parallel with C is given by—

$$Z_1 = \frac{1}{\frac{1}{r + jpl} + jpC}$$

The total impedance Z is given by—

$$Z = Z_1 + R.$$

Also—

$$e = Z_1 \times i_r \quad \text{and} \quad i_r = E/Z.$$

Hence—

$$e = E\frac{Z_1}{Z} = E \cdot \frac{Z_1}{Z_1 + R}.$$

The current i is therefore given by—

$$i = E\left(\frac{Z_1}{Z_1 + R}\right)\left(\frac{1}{r + jpl}\right).$$

Substituting for Z_1 and converting into real form, we get after some reduction—

$$E^2 = i^2\left(R^2 . \overline{p^2 C^2 r^2 + (1 - p^2 C l)}^2 + r_2 + p^2 l^2 + 2Rr\right).$$

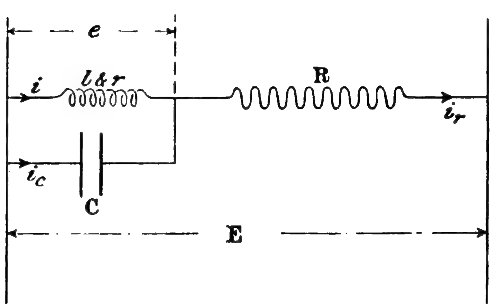


FIG. 5.

Now if the instrument is to read correctly on continuous- and alternating-current circuits—

$$R^2 \overline{p^2 C^2 r^2 + (1 - p^2 C l)}^2 + r^2 + p^2 l^2 + 2Rr \quad \text{must} = (R + r)^2$$

or—

$$p^2 C^2 r^2 R^2 - 2p^2 R^2 C l + p^4 C^2 l^2 R^2 + p^2 l^2 = 0.$$

Rearranging this we get—

$$C^2 - 2C \cdot \frac{l}{r^2 + p^2 l^2} + \frac{l^2}{(r^2 + p^2 l^2) R^2} = 0.$$

Solving for C gives—

$$C = \frac{l}{r^2 + p^2 l^2}\left(1 \pm \sqrt{1 - \frac{r^2 + p^2 l^2}{R^2}}\right) \text{ farads.}$$

For all ordinary frequencies $r^2 + p^2 l^2$ will be less than R^2, and hence the above equation will give two positive values for C.

For the previously mentioned 220-volt recorder, the values of C as obtained from the formula are:—

For a frequency of	100, C = 0·0936 microfarad	and	3·2 microfarads,
,, ,,	50, C = 0·092 ,,	,,	5·64 ,,
,, ,,	25, C = 0·0918 ,,	,,	6·97 ,,

and for the 110-volt instrument—

For a frequency of	100, C = 0·312 microfarad	and	14·8 microfarads,
,, ,,	50, C = 0·31 ,,	,,	29·5 ,,
,, ,,	25, C = 0·308 ,,	,,	39·0 ,,

As showing how nearly these results agree with practice, it may be stated that a capacity of 0·1 microfarad was required to compensate the 220-volt instrument, and 0·3 microfarad to compensate the 110-volt instrument. Moreover, on a 100-frequency circuit a capacity of 3·2 microfarads accurately compensated the 220-volt instrument.

It may seem strange at first sight that there are two values of C which will destroy the effects of the self-induction of the coils. The reason for this, however, is clearly seen on referring to the vector diagram Fig. 6 which has been drawn for the case of the 220-volt recorder on a 100-frequency circuit.

In this case, as before, the current through the coils has to be 0·0821 ampere when 220 volts are applied to the terminals of the instrument. The "drop" over the coils is therefore 60 volts, leading the current by 49°. The values of the capacity required to compensate are 0·0936 microfarad and 3·2 microfarads. Hence the condenser currents are 3·525 milliamperes and 120·5 milliamperes respectively. Combining these with the current passing through the coils, we get the total current through the non-inductive resistance R. Thus the drop over this is fixed in magnitude and direction, and by adding the drop over the coils we arrive at the terminal voltage, which is seen to be 220 volts in both cases.

In conclusion, then, it may be said that the dynamometer forms a valuable sub-standard for laboratory work, whether as amperemeter, voltmeter, or wattmeter. In fact, of the various types of instrument suitable for use on both continuous-current and alternating-current circuits this undoubtedly can be made to give the most accurate results.

For recording voltmeters the dynamometer is far superior to the soft-iron instrument, the only other class of instrument which

can be adopted for recorders and which is, at the same time, suitable for continuous- and alternating-current circuits. For recording amperemeters, on the other hand, as has been pointed out, the dynamometer cannot be well adopted where a universal instrument is required, as the shunt drop would be very excessive. In this particular instance, the

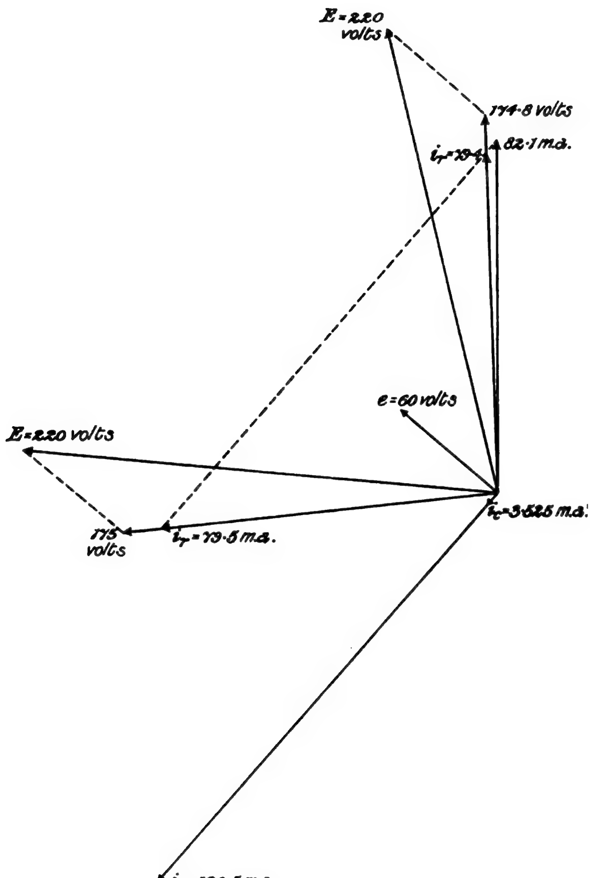


FIG. 6.

soft-iron instrument, no doubt, has the advantage. For such an instrument can easily be wound to carry currents up to 500 amperes, and if care is taken to laminate the winding, and at the same time to reduce eddy current and hysteresis loss in the iron, a fair degree of accuracy will be maintained both on continuous- and alternating-current circuits.

HYSTERESIS LOSS IN IRON TAKEN THROUGH UNSYMMETRICAL CYCLES OF CONSTANT AMPLITUDE.

By M. Rosenbaum, B.Sc., Associate Member.

(*Received 16th December*, 1911; *received in final form*, 19*th January*, 1912.)

The following experiments were undertaken with a view of ascertaining how the iron losses of a static transformer vary, due to the superposition of direct-current magnetisation on the alternating flux.

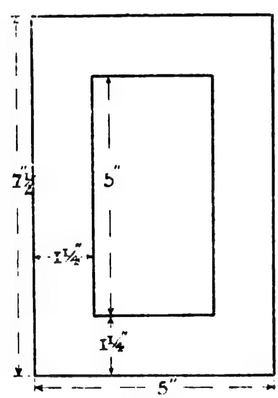


Fig. 1.

The change of flux over a cycle was maintained constant throughout the experiment.

Experimenters have usually confined their attention to the effect on the hysteresis loss of constant change of magnetising current,* and very little has been done with constant change of magnetic flux, a case which frequently appears in practice.

Dr. Coales † has proceeded along lines similar to those in the present paper, but has not investigated the effect on the hysteresis loss due to the different cyclic changes.

* *Philosophical Transactions of the Royal Society*, vol. 184, p. 985, 1893.

† "On a Method of using Transformers as Choking Coils," *Journal of the Institution of Electrical Engineers*, vol. 42, p. 412, 1908.

The transformer tested was a $\frac{3}{4}$-k.w. core transformer, the primary of which consisted of two windings, each of 128 turns, while the secondary consisted of eight separate windings each of 25 turns. The core of the transformer consisted of 325 stampings of dimensions as shown in Fig. 1, the mean thickness of each plate being 14 mils. The total cross-section of iron in the magnetic circuit was 36·8 sq. cm., while the mean length of the magnetic path was approximately 50·8 cm. The total weight of iron employed was 14·1 kg., while that of the copper was 13·6 kg. The source of supply was an 8-k.w. rotary converter whose E.M.F. wave had approximately a sine shape (see Fig. 8A).

The diagram of connections is given in Fig. 2, where—

A_1 = Hot-wire ammeter.
W = Mather-Duddell wattmeter.
T_1 = Auxiliary transformer.
P = Primary of transformer under test.
S_1 S_2 = Sections of secondary of transformer.
R S = Reversing switch.
A_2 = Moving-coil ammeter.
C = Ironless choking coils.
R = Adjustable resistance.
Sw = Switch.

The flux wave had approximately a sine shape throughout the experiment. To ensure this the potential difference applied to the transformer had to have a sine shape. This was obtained by having as small a resistance as possible in the alternating-current side of the converter.

The auxiliary transformer T_1 was employed to step-down the voltage of the converter to the required amount (the alternating-current voltage of the converter being too high). Fine adjustments in the voltage were obtained by means of an adjustable resistance in the direct-current side of the rotary converter. Thus, with the exception of the instruments which had a low resistance, no resistance was placed in the alternating-current side of the circuit. The reversing switch (R S) was employed in order to bring the iron to a steady cyclic state, since it was possible that some residual magnetism remained in the iron, especially when the superposed ampere-turns were large in number.

As is seen in the figure, the battery is placed in the secondary circuit of the transformer. It was impossible to place it in the primary circuit, since it needed an adjustable resistance to vary the direct current, and as resistance in the primary circuit was inadmissible, this could not be done. It is seen that the battery circuit forms a closed secondary path in the transformer, and thus induced currents are produced in this circuit which result in additional copper losses, which must be taken into account.

In order to reduce these losses to a small amount, several large

ironless choking coils were placed in series in the secondary coil circuit. These coils offer a very large impedance to alternating current and practically none to direct current. All metal was also excluded from the framework of these coils, so that there should be no increased losses in the secondary coil circuit due to hysteresis or eddy-current losses in any metal of these choking coils.

The additional copper loss in the secondary circuit due to the alternating current was ascertained by including in this circuit a switch (Sw), by means of which the cells could be cut out of the

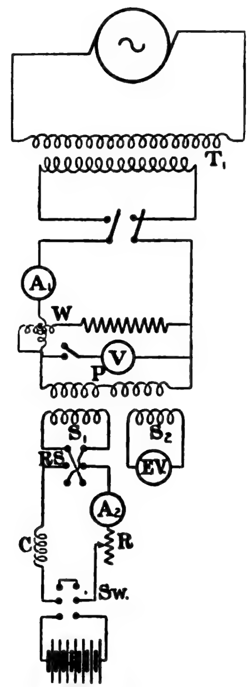


FIG. 2.

circuit. The cells having a very low resistance did not appreciably alter the impedance of the secondary circuit.

The following procedure was adopted to ascertain these additional copper losses. A reading of the wattmeter was taken with the secondary circuit open. The switch (Sw) was then placed in the "up" position and the reading again taken. If these two readings differed it showed that there were additional copper losses, which were taken into account and deducted from the wattmeter reading in order to obtain the true iron losses in the transformer. These losses were found to be inappreciable when S_1 contained few turns, but as

these turns were increased the losses became appreciable, since they are approximately proportional to the square of the number of turns.

In order to ascertain whether there was any appreciable magnetic leakage as the direct-current ampere-turns were increased, an electrostatic voltmeter was placed across part of the secondary of the transformer. In the experiments the applied voltage was kept constant at 100 volts and the frequency at 50 cycles per second. The following table gives the results obtained :—

Direct-current Ampere-turns.	Magnetising Current.	Total Watts. Iron + Primary Copper.	Iron Losses.	Power Factor.
				Per Cent.
0·0	0·30	20·5	20·5	68·0
25·0	0·39	21·0	21·0	53·8
50·0	0·49	22·5	22·5	45·9
100·0	0·70	24·8	24·7	35·4
150·0	0·94	27·0	26·8	28·7
200·0	1·20	29·0	28·6	24·1
250·0	1·45	30·8	30·2	21·2
297·5	1·75	32·0	31·2	18·3
500·0	2·60	36·0	34·2	13·8
750·0	3·80	39·6	35·5	10·4
1,250·0	6·20	47·2	36·8	7·6

The secondary voltage as given by the electrostatic voltmeter remained practically constant throughout the experiment at 19·5 volts.

Fig. 3 shows the relationship between the direct-current ampere-turns applied and (A) the magnetising current, (B) the total iron losses, and (C) the power factor.

Since the back E.M.F. and the wave-form of the back E.M.F. remained practically constant, the total change of flux density per cycle remained practically constant. This was calculated from the known primary turns and cross-section of iron, and found to be 9,600 lines per square centimetre assuming a sine-wave of flux.

The eddy-current losses depend on the square of the flux density, and as this remained practically constant, as shown by the electrostatic voltmeter, the eddy-current losses are approximately constant throughout, although a slight change might be expected due to the eddy currents induced in the copper of the windings and also due to the slight deviation from a sine wave of the magnetic flux. The leakage flux is very small, as shown by the constancy of the secondary volts, and therefore the losses due to any leakage flux are negligible, due to the entire absence of metal surrounding the transformer.

The constant eddy-current losses were experimentally found to be 4·5 watts. This was ascertained by obtaining various values of the total iron losses with constant applied potential difference of sine-wave

shape, and therefore constant flux at different known frequencies. In this way it was possible to separate out the hysteresis from the eddy-current loss, since the hysteresis loss is proportional to the frequency, while the eddy-current loss is proportional to the square of the frequency.

The additional iron losses when direct-current ampere-turns were superposed can therefore be attributed only to the increased hysteresis loss in the iron. This was verified experimentally by taking the iron through the same changes with direct current as occurred with the alternating current, and obtaining the loop by the ballistic method. In all the loops so taken the total change of flux density was maintained at 9,600 lines per square centimetre, as was the case in the alternating-current tests.

Four loops were taken altogether in this way with maximum induction densities of :—

(A) 4,800	lines per square	centimetre.
(B) 10,300	„	„
(C) 13,000	„	„
(D) 15,400	„	„

Three of these loops, viz., (A), (B), and (D), together with the saturation curve of the transformer, are shown in Fig. 4. The procedure adopted in finding these loops was as follows :—

A current was sent round part of the windings of the transformer so as to obtain the particular maximum of the flux density required. The galvanometer scale having been previously calibrated, this current was suddenly reduced to such a value as to obtain a change of flux density of 9,600 lines per square centimetre. These two values of the current gave the extreme values of the current for the loop required. Intermediate values of the top part of the loop were obtained by suddenly reducing the maximum value of the current to intermediate values and obtaining the throws on the galvanometer scale, care being taken that the iron in each case was in a condition corresponding to the loops under consideration. The bottom part of the loop was obtained by bringing the current up to its maximum value corresponding to the loop. This current was then reduced to the minimum value. This minimum value was then suddenly raised to various values intermediate between the minimum and the maximum and the throws on the galvanometer noted; in this case also care was taken that the iron was in every case in the condition corresponding to the loop under consideration.

From these loops the hysteresis losses have been determined, assuming a frequency of 50 cycles per second, as this was the frequency employed in the wattmeter method. From loop (D) and assuming a sine-wave of flux, the shape of the magnetising current wave-form has been obtained as shown in Fig. 5, the corresponding ampere-turns to a particular value of the flux being obtained from the loop.

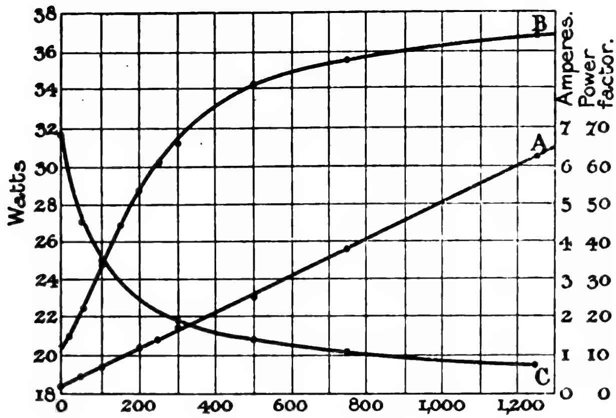

Watts
38
36
34
32
30
28
26
24
22
20
18
0
200
400
600
800
1,000
1,200
Amperes.
Power factor.
7 70
6 60
5 50
4 40
3 30
2 20
1 10
0 0
A
B
C

FIG. 3.

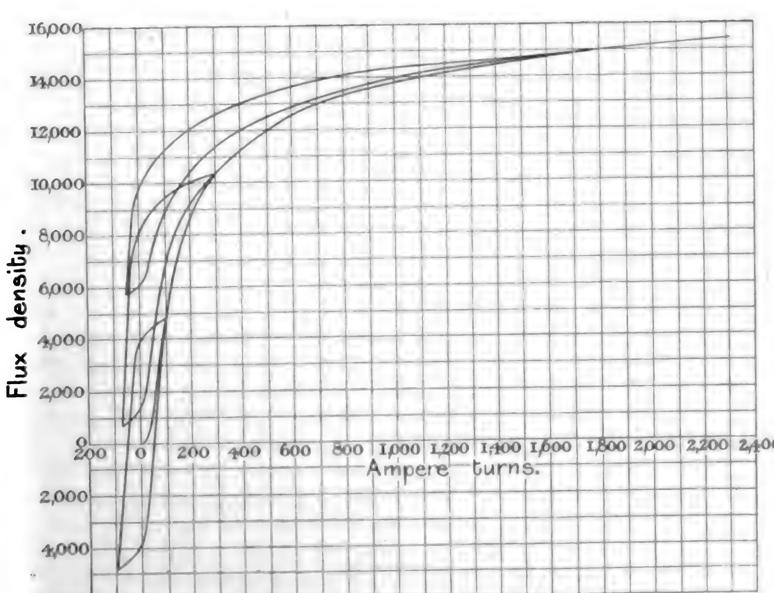

Flux density.
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
2,000
4,000
6,000
200
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
Ampere turns.

FIG. 4.

The areas above the zero-line in the magnetising-current wave-form must be equal to the area below the zero-line, since the same quantity of electricity flows into the transformer as comes out of it; the line B_1B_2 was consequently deduced to make these areas equal. The distance between A_1A_2 and B_1B_2 therefore gives the direct-current ampere-turns A T superimposed. Thus the loss as found by the loop (D) in the ballistic method corresponds with that obtained in the alternating-current tests when direct-current ampere-turns of values given by the distance between the lines A_1A_2 and B_1B_2 in Fig. 5 were superposed.

This value, therefore, becomes known from the known scale of ampere-turns in the loop D. Similarly these ampere-turns were obtained for loops (A), (B), and (C). It was necessary to compare the hysteresis loss obtained by the alternating-current method with the results obtained by the ballistic method. For this purpose the losses when using alternating current were separating into eddy-current losses and hysteresis, the former being approximately constant as the change of flux was constant, and the flux-wave maintained practically a sine shape throughout.

The following gives the tabulated results :—

Direct-current Ampere-turns.	Alternating-current Test. Total Iron Losses – Eddy-current Losses.	Hysteresis Loss from Loops.
	Watts.	Watts.
0	16·0	15·8
55	18·3	18·0
145	22·4	20·8
500	29·7	27·5

It is seen that there is a fairly close agreement in the last two columns, showing that the increased loss in the alternating-current test is chiefly due to the increased hysteresis loss. The discrepancy which occurs in the readings by the two methods is probably chiefly due to the assumptions made and also in taking approximate values in working out the loss by the ballistic method. For example, the flux wave was considered to be sinusoidal, which is only approximately true, and this would affect the computed ampere-turns as shown in Fig. 5.

Again, the mean length of the magnetic circuit was considered to be the same throughout in the ballistic test in finding the hysteresis loss from the loops obtained. In the alternating-current test the flux will not be uniformly distributed throughout the core of the transformer, and its distribution will alter as direct-current magnetisation is superposed on the alternating flux; thus in the alternating-current

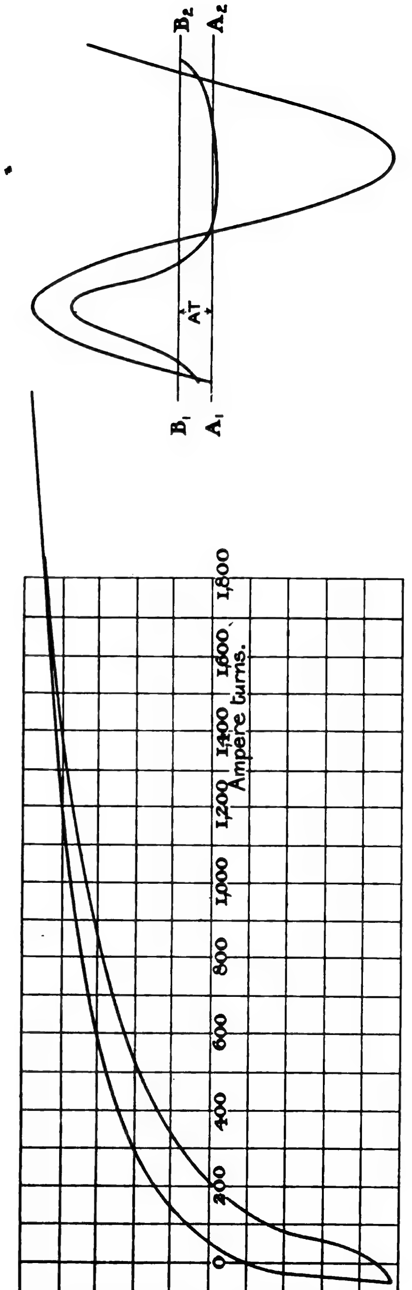

B₂
A₂
B₁
A₁
AT
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
Ampere turns.

Fig. 5.

tests the exact value of the mean length of the magnetic path in the core is unknown and varies as direct-current ampere-turns are superposed, whereas this has been assumed constant and equal to 50·8 cm.

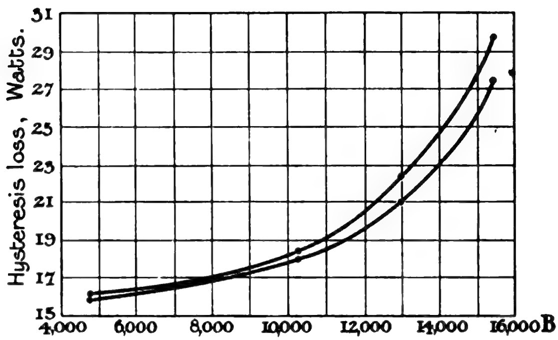


FIG. 6.

in the ballistic test. It is probable that, could all the conditions be accurately taken into account, a much closer agreement would be found in columns 2 and 3.

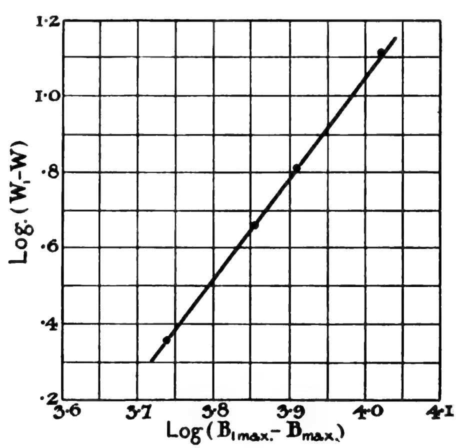


FIG. 7.

Fig. 6 gives the relationship between the maximum induction density to which the iron is raised and the hysteresis loss as found by the two methods. It is seen that the hysteresis loss increases slowly at first and more rapidly afterwards, the small increase occurring during the steep portion of the "saturation" curve while the large increase

takes place after the "bending-over" point is reached, which is chiefly due to the large change in ampere-turns necessary for the required change of flux density.

The hysteresis loss as found by the wattmeter method appears to follow the law—

$$W_1 - W = a\,(B_{1\,max.} - B_{max.})^C,$$

where—

W_1 = hysteresis loss at maximum induction density $B_{1\,max.}$

and—

W = hysteresis loss for the symmetrical loop of maximum induction density $B_{max.}$ (when no direct-current magnetisation is superposed).

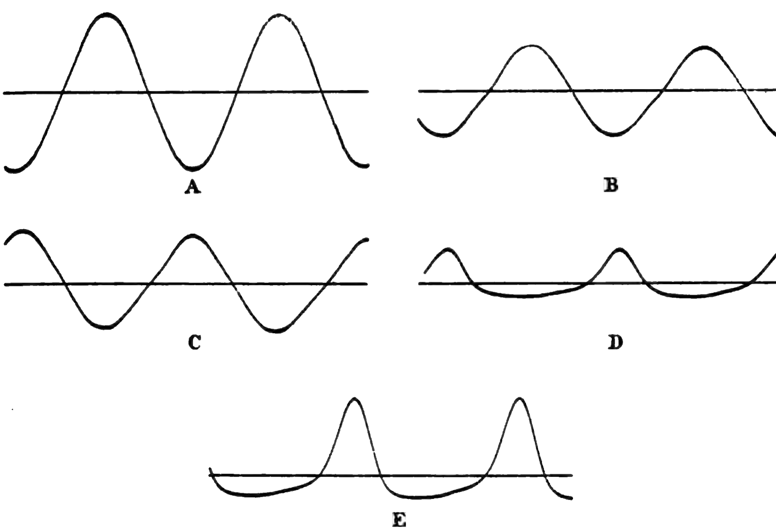


FIG. 8.

In the test under consideration—

$$a = 4{\cdot}3 \times 10^{-10}$$
$$C = 2{\cdot}6.$$

The relationship between log $(W_1 - W)$ and log $(B_{1\,max.} - B_{max.})$ is shown in Fig. 7. In this connection it is interesting to note that the relationship between the ampere turns superposed and the root mean square of the magnetising current follows a straight-line law.*

* *Journal of the Institution of Electrical Engineers*, vol. 42, pp. 432 to 454, 1908.

In Fig. 8 are shown some oscillograms which were taken—

(*a*) The applied potential difference of the converter.
(*b*) The secondary E.M.F. with 625 ampere-turns superposed.
(*c*) The secondary E.M.F. with 1,350 „ „
(*d*) The magnetising current with 300 „ „
(*e*) The magnetising current with 600 „ „

The applied potential difference is seen to give practically a sine wave. The current waves are seen to resemble that obtained in Fig. 5. The E.M.F. waves and the flux waves do not differ much from a sine wave. The deviation is due to the copper drop in the primary of the transformer. If the resultant of the applied potential difference and

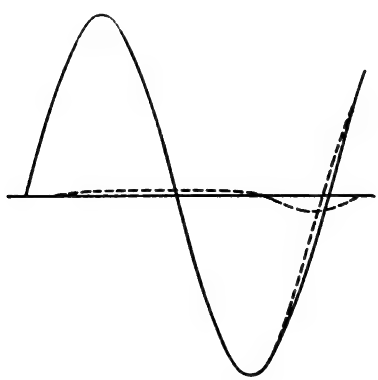


FIG. 9.

the copper drop be found, it will be found to resemble the E.M.F. wave as shown in B and C, Fig. 8. This has been done approximately in Fig. 9.

It is this copper drop which prevents one from investigating the losses for very large superposed ampere-turns, since with a sine-wave of applied potential difference the flux-wave no longer has a sine shape and also the variation in flux density per cycle does not remain constant.

CONCLUSIONS.

It is seen that the hysteresis loss increases very appreciably as direct-current magnetisation is superposed on the alternating flux. This phenomenon manifests itself in practice in inductor alternators and static balancers. In some kinds of inductor alternators the flux does not reverse, but oscillates between a positive maximum and positive minimum value, thus the iron loss per cubic centimetre is

much greater in inductor alternators than in the ordinary type for the same change of flux in the armature coil.

In static balancers this effect also takes place where the direct-current magnetisation is not neutralised. It is therefore important, if high efficiency be aimed at, to neutralise the direct-current flux. Any difference in the resistance of the limbs of the balancer tends to throw out the balancing of the direct-current flux. The resistance of the windings of a static balancer is usually extremely small, and thus any difference in the lengths of the leads or inclusion of any measuring instrument in, say, one limb only is liable to create a large amount of direct-current magnetisation in the core of the static balancer and thus lowers its efficiency.

THE LOSSES IN INDUCTION MOTORS ARISING FROM ECCENTRICITY OF THE ROTOR.

By CHARLES F. SMITH, Member, and ERIC M. JOHNSON, Student.

(*Paper received 27th December*, 1911.)

CONTENTS.

In a previous paper * attention was called to some effects of eccentricity of the rotor in induction motors, in particular to the resulting uneven distribution of voltage in the stator winding, and to the high saturation of the teeth situated in the field of the narrow part of the air-gap. Other consequences of rotor eccentricity, which were referred to, are the magnetic pull exerted on the rotor, the increased iron losses due to the uneven field distribution, and increased copper losses in the rotor due to circulating currents.

The research described in the following paper was undertaken with the object of ascertaining the magnitude of the additional losses in a motor brought about by a progressive increase in the eccentricity of the rotor, and of thus obtaining information as to the amount of eccentricity which may be allowed in practice without serious disadvantage.

Nature of Losses due to Rotor Eccentricity.—Briefly, the eccentricity of the rotor tends to produce an increase in the density of the air-gap flux where the length of the air-gap is decreased, and a weakening of the flux where the gap is increased by the displacement of the rotor. This disturbance of the symmetry of the flux entering the rotor gives rise to electromotive forces in the rotor winding, which in turn tend to set up circulating currents of such a character as to neutralise the unsymmetrical flux and to restore the uniformity of the rotating field.

* C. F. Smith, "Irregularities in the Rotating Field of the Polyphase Induction Motor." *Journal of the Institution of Electrical Engineers*, vol. 46, p 132, 1911.

The extent to which these circulating currents can be actually formed, and, in consequence, the extent to which the eccentricity of the rotor actually produces dissymmetry of the rotating field, depend upon the type of rotor winding employed.

With a squirrel-cage or multiple-circuit rotor winding, the circulating currents are developed freely, and to a great extent neutralise the disturbing influence of inequality of the air-gap. With a series form of rotor winding, on the other hand, the introduced electromotive forces due to unevenness of the air-gap largely balance one another in the winding, and little compensating action can result.

It thus appears that there will be two kinds of loss arising from eccentricity of the rotor, viz.: (1) Iron losses due to local concentration of flux in the teeth and cores of the stator and rotor where the air-gap is small; and (2) copper losses produced by the circulating rotor currents. A third source of loss may arise from friction caused by the additional pressure on the bearings, if the eccentricity is sufficient to produce considerable magnetic pull on the rotor core.

Outline of Experiments.—The experiments were carried out on a 3-phase induction motor which had been provided with end-plates capable of vertical adjustment, so that the eccentricity of the rotor could be varied.

For determining the possible range of iron losses, the induction motor was first coupled to a continuous-current motor. The rotor was open-circuited, and the stator supplied with alternating current. The machines were then driven at various speeds with the rotor eccentricity adjusted to a number of differing values. The effect of the change in eccentricity upon the iron losses under these conditions was deduced from observations of the power taken by the driving motor.

The distribution of flux round the air-gap with various eccentricities was next examined with the rotor stationary.

Subsequently, observations were made with two types of closed winding on the rotor. The running losses and the stationary flux distribution were taken for each type. Oscillograms were taken on search coils situated on the rotor to illustrate further the distribution of the flux round the air-gap with varying displacements of the rotor. In the following summary the sequence of the observations has been slightly varied.

Description of Motor Employed.—The motor used in the experiments was a 4-pole, 3-phase motor made by the Oerlikon Company, and originally rated to give 3 H.P. at 200 volts on a 50-cycle circuit. In the motor as originally made, the rotor slots were closed; but, in order to allow of a wider range of movement of the rotor, the rotor winding was removed and the core turned down, so that the actual shape of the slots during the experiments was as shown in Fig. 1. The new air-gap length was 0·063 in. with the rotor central. The stator had 48 slots wound with 8 wires per slot. The rotor was rewound with No. 11 S.W.G. double-cotton-covered wire, 4 wires per slot in 36 slots. The ends of this winding were at first left open, and were subsequently

soldered together, so as to form a closed winding. The winding was closed successively in two different ways, so as to form respectively a single- and a multiple-circuit type of winding. The rotor was not provided with slip-rings.

Alteration of the eccentricity of the rotor was carried out by swivelling each end-plate about one of the bolts (carefully fitted for this purpose) passing through its flange. The holes of the other flange bolts were enlarged to allow of the necessary movement. A micrometer gauge fixed on each flange of the stator was used to indicate the vertical movement of a plane surface which had been filed at the top of the flange of each end-plate. The bolts which acted as the pivots, about which the rotor was swung through a small angle, were in the same horizontal plane as the centre of the rotor shaft. A calculation showed that the vertical movement registered by the gauges could be safely taken to represent the actual displacement of the rotor from its central position. By means of the micrometer, displacements could be measured to one two-thousandth of an inch.

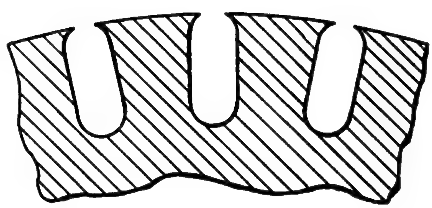


FIG. 1.—Slots of Rotor (Actual Size).

Flux Distribution with Rotor Winding Open.—The distribution of the flux round the air-gap was first measured with the rotor stationary. This was done with the rotor lowered by varying amounts from its central position.

For this purpose, a search coil was wound in two of the rotor slots having a pitch equal to one-quarter of the rotor circumference, *i.e.*, one pole-pitch. Voltage was supplied to the stator winding, and the voltage induced in the search coil was observed, as the rotor was rotated into a series of positions. For purposes of comparison with subsequent observations, the stator voltage was maintained at only 30 volts. It was found, however, that when the stator voltage was raised to five times this value, the ratio of the search coil voltages to the stator voltage was practically unaltered.

The search coil voltages observed with the rotor in each of twenty-four successive positions are plotted in Fig. 2. The five curves give the observations for four values of the eccentricity and for the central position of the rotor. The ordinates of the curves may be taken to represent the values of the flux which passed through an arc of the air-gap equal in length to one pole-pitch. The numerals marked along the hori-

zontal axis represent the positions of the coil relatively to the stator, position 4 being that corresponding to the narrowest gap, and position 10 to the widest gap.

It is of interest to notice how nearly the variation of the flux indicated by the amplitude of the curves shown in Fig. 2 corresponds to changes in the mean length of the air-gap, due to displacement of the rotor.

It can be shown geometrically* that the average length of the

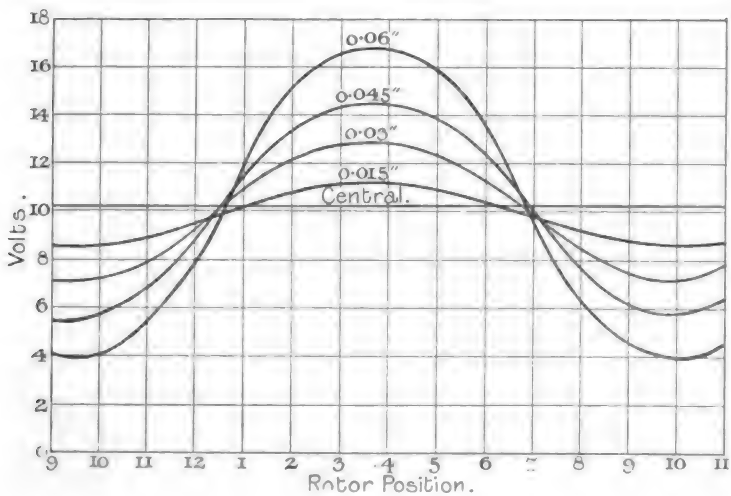


FIG. 2.—Flux Distribution for various Displacements of Rotor.

Rotor stationary and open-circuited. Applied voltage = 30.
Figures on curves show amount of displacement. Normal air-gap = 0·063 in.

maximum and minimum air-gaps subtending one pole-pitch of a 4-pole motor have values given approximately by the expression—

$$x = g \pm 0{\cdot}9\, a \quad \dots\dots\dots \quad (1)$$

where—

x is the average length of the air-gap taken over one pole-pitch at the top or bottom of the motor;
g is the original gap with central rotor;
a is the displacement of the rotor from its central position.

By inserting the positive sign in the formula, we obtain the value of the average air-gap corresponding to the lowest points on the curves; by using the negative sign, the values correspond to the upper points.

If the reluctance of the path followed by the magnetic lines were proportional to the length of the air-gap, the maximum and minimum

* See Appendix.

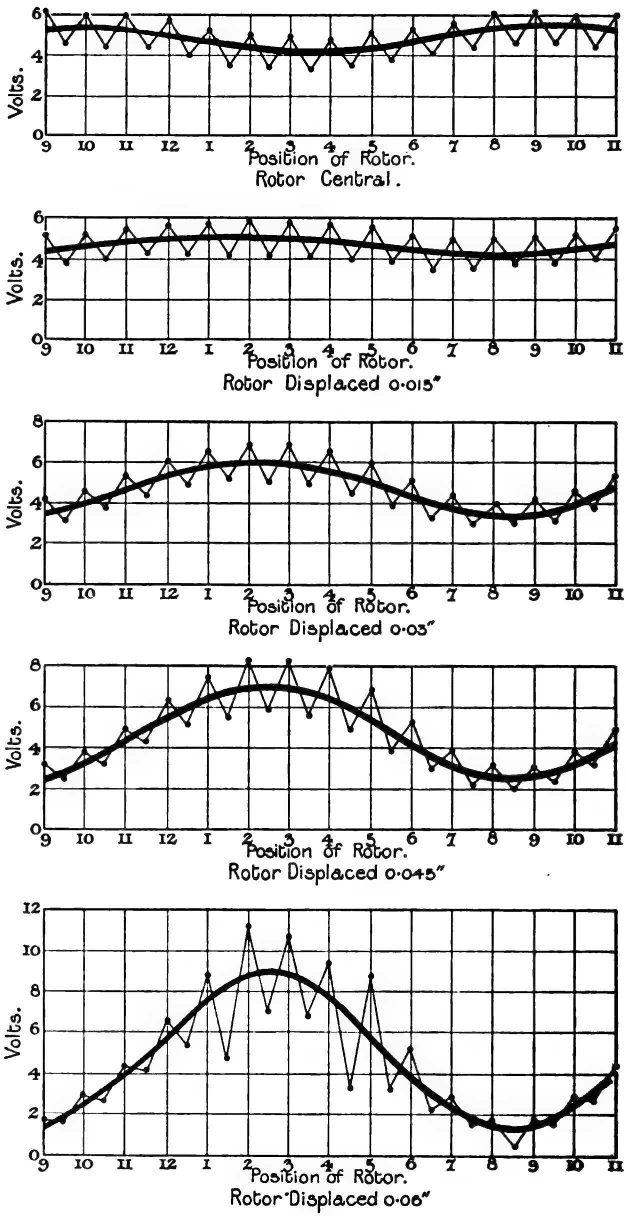


FIG. 3.—Curves of Flux Distribution.

Rotor stationary and short-circuited.
Single-circuit-per-phase winding.

Applied volts = 30.
Normal air-gap = 0·063 in.

values of the curves in Fig. 2 should agree nearly with the following expression derived from the equation just given :—

$$v_m = \frac{v\,(g \pm 0{\cdot}9\,a)}{g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

where—

v is the voltage observed with the rotor central (= 10·2 volts);
v_m represents the maximum or minimum values with eccentric rotor.

Owing to the reluctance of other parts of the magnetic circuit, especially that due to the slots which lengthen the path followed by the flux across the air-gap and produce saturation of the teeth, the value of g in the equation (2) must be increased.

The observed maximum and minimum values agree fairly well with those of the formula, if the air-gap length, g, is taken about 30 per cent. greater than its actual value, in order to allow for the increase in reluctance due to the slots, etc. A still closer agreement between the calculated and observed values can be secured by making this correction different for the upper and lower points, where the degrees of saturation are respectively above and below the average. It should be remembered that the teeth of the motor experimented on were somewhat abnormal owing to their having been turned down below their original dimensions, and that the correction would otherwise not have been so large.

Flux Distribution with Rotor Winding Closed.—Similar observations to the last were taken with a closed winding on the rotor, in order to show the modifications produced in the field by the currents set up in a short-circuited rotor winding. The rotor was stationary in this case also.

The rotor winding consisted of No. 11 S.W.G. double-cotton-covered wire, 4 wires per slot, wound to give 6 coils, 2 per phase, with 12 turns per coil.

Tests were made with the rotor winding short-circuited in two different ways : (*a*) each phase-winding (consisting of two coils having a common axis, but situated on opposite sides of the rotor) was closed on itself to form a single circuit ; (*b*) each coil was closed on itself, so that the rotor winding consisted of six separately short-circuited coils.

With the first type of winding, a coil situated in the narrowest part of the air-gap would always be in series with a coil situated in the widest air-gap. With the second arrangement of connections, the current in any coil would be the result of the voltage induced in that coil alone.

The connection (*a*) was intended to represent the single-circuit-per-phase type of winding usually adopted with wound rotors. Connection (*b*) represented the multiple-circuit connections usually found in rotors which are not provided with slip-rings, including squirrel-cage rotors.

The results obtained with winding (*a*) are shown in Fig. 3, and those with winding (*b*) in Fig. 4.

With a short-circuited winding on the rotor, large variations in the

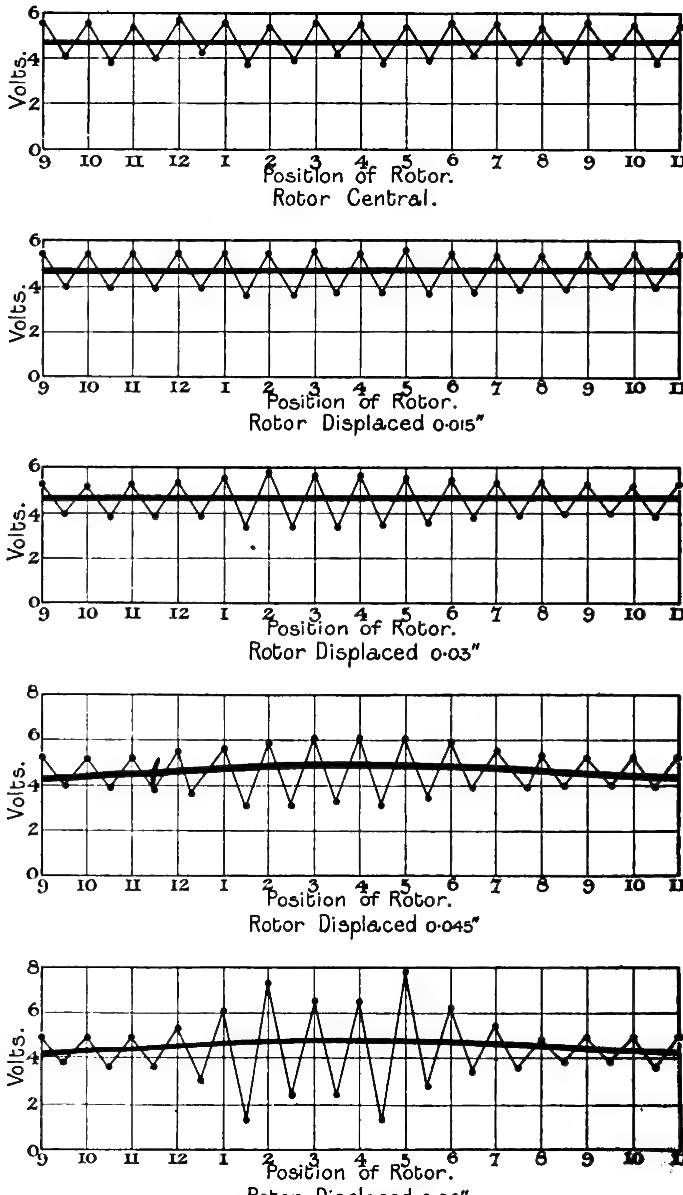


FIG. 4.—Curves of Flux Distribution.

Rotor stationary and short-circuited.
Multiple-circuit winding.

Applied volts = 30.
Normal air-gap, 0·063 in.

search-coil voltages were produced by small changes in the relative positions of the stator and rotor teeth, giving a "saw-tooth" appearance to the curves. These effects are clearly seen in Figs. 3 and 4, where maximum and minimum values are shown as occurring alternately at 24 points in the rotor circumference. A mean curve has been drawn between the observed values to represent the approximate variations of the total polar flux arising from the rotor eccentricity. With the rotor winding open (see Fig. 2) the rapid fluctuations just referred to were only slight, showing that the "cogging" effect is due to the concentration of the currents in the slots rather than to variations in reluctance arising from the relative positions of the teeth of the stator and rotor cores. This bears out the conclusions already drawn in the paper cited at the beginning of the present communication as to the slight effect on the polar flux of variations of air-gap reluctance due to this cause.

On comparing the curves obtained without current in the rotor (Fig. 2) with those taken under similar conditions and at the same applied voltage, but with a short-circuited winding of type (*a*), it is seen that, while the actual flux in the air-gap is considerably reduced by the loss of voltage resulting from the flow of current through the impedance of the windings, the ratio of maximum to minimum voltage in the search coil is practically the same as when the rotor winding was open.

This indicates that with the single-circuit winding the rotor currents have no appreciable effect in diminishing the inequality of the air-gap flux, which results from an eccentric position of the rotor; they exert no sensible "compensating" action.

Fig. 4 shows the flux variation round the stator with connections of type (*b*) on the rotor, *i.e.*, each coil separately short-circuited. A glance at the mean curve shows that the rotor currents have an almost complete compensating action in this case, and that they maintain a practically uniform flux distribution in the air-gap, which is consequently almost unaffected by the eccentricity of the rotor.

In order that this compensation may be effected, the rotor winding must carry bands of current flowing round a vertical axis in such a manner as to reinforce the main field where the air-gap is greatest, and to weaken it where the air-gap is least.

An attempt was made to measure this additional magnetising current by inserting an ammeter in series with one of the rotor coils. The resistance of the ammeter and of the necessary flexible leads disturbed the distribution of the currents in the rotor windings too much to allow of any useful quantitative measurements being made. It was, however, clearly shown that a variation in the rotor current of the expected kind did occur when the rotor coils were short-circuited, and that with series-connected coils the current distribution in the rotor was practically uniform and independent of inequality of the air-gap. A theoretical estimate of the value of the balancing currents induced in the rotor winding by eccentricity is given later.

Iron Losses with Rotor Winding Open.—The effect which the existence

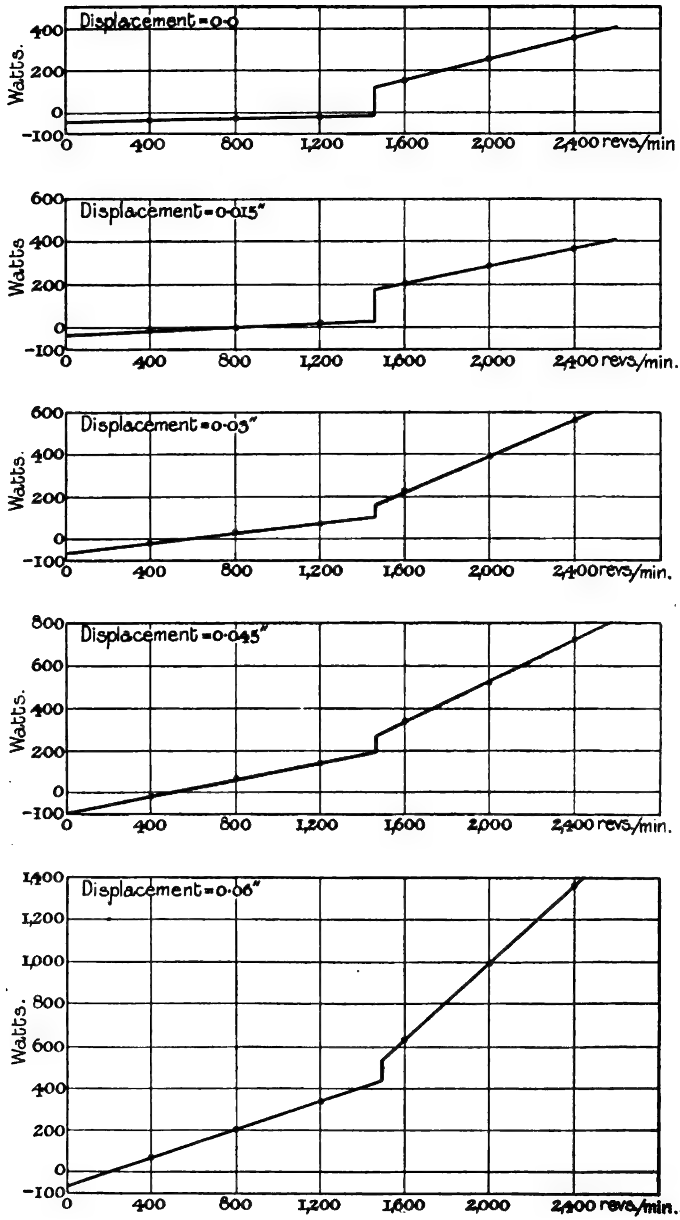


FIG. 5.—Curves of Rotor Iron Losses.

Rotor open-circuited. Voltage on stator = 250.
Normal air-gap = 0·063 in.

of a non-uniform field in the air-gap has upon the iron losses of the motor was determined experimentally by driving the open-circuited rotor by a continuous-current motor. The increase in the driving power taken by the continuous-current motor on switching on the alternating-current supply to the stator of the induction motor was observed and plotted for various speeds of the machines. The observa-

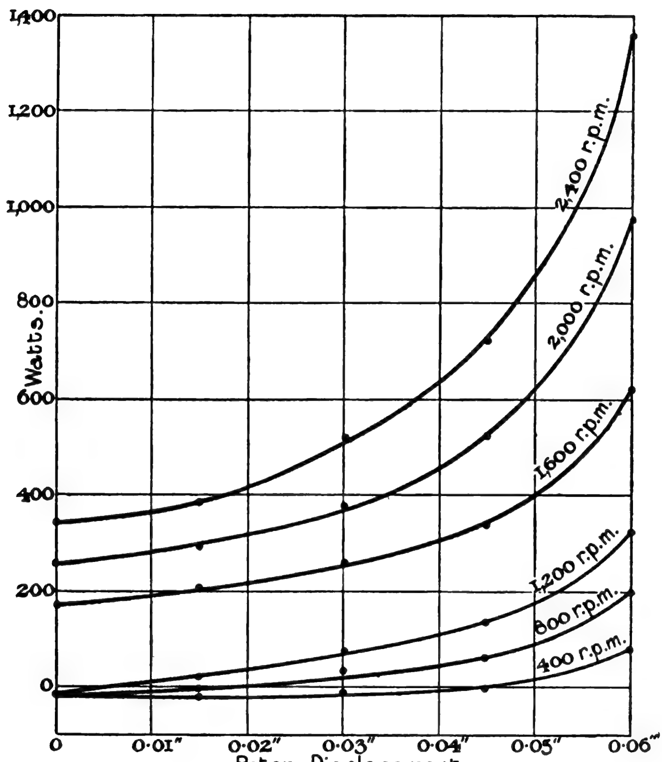


FIG. 6.—Curves of Rotor Iron Loss.

Rotor open-circuited. Voltage on stator = 250.
Normal air-gap = 0·063 in.

tions were repeated for several values of the rotor eccentricity. In Fig. 5 are given some curves showing the results obtained in this way when an alternating voltage of 250 was applied to the stator.

If the motor were working under normal conditions, the losses which are here plotted would appear in the motor as an increase in the load to be overcome at the expense of a part of the power given electrically to the rotor. These losses consist practically of the rotor iron

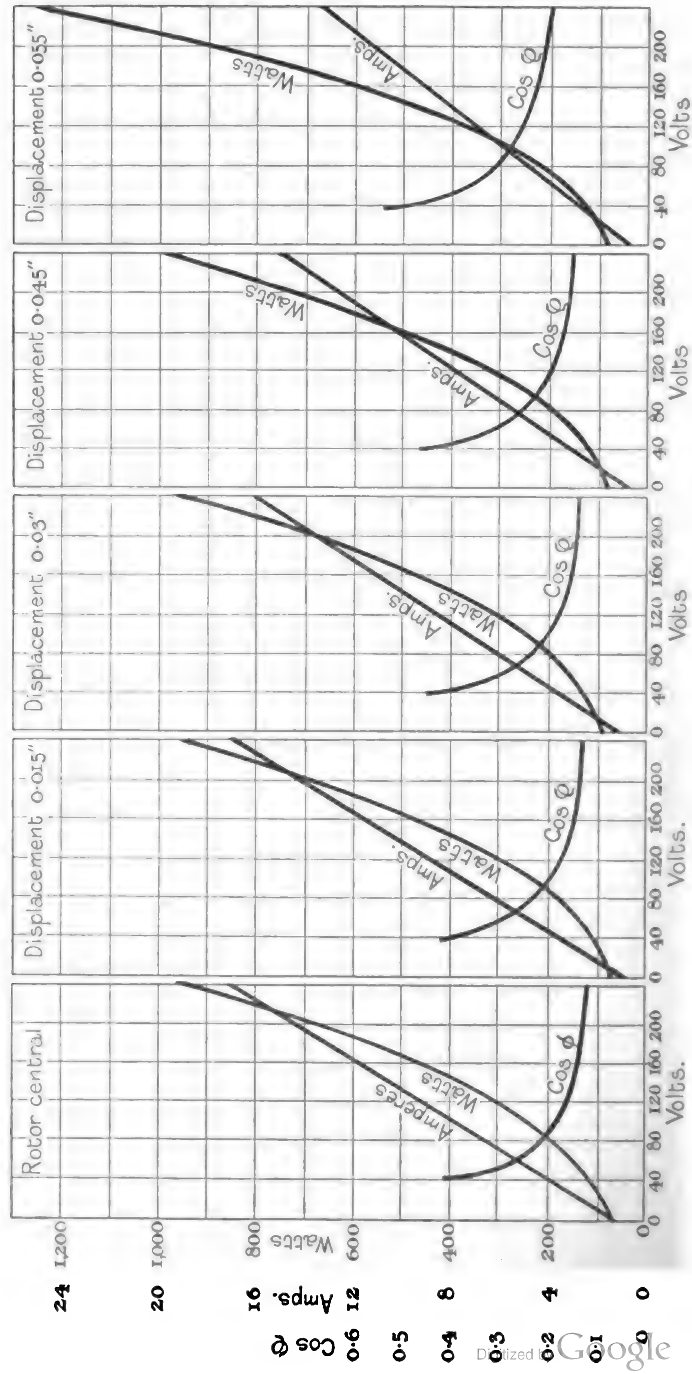


FIG. 7.—Curves of Current, Power, and Power Factor. (Motor running light.)

Single-circuit-per-phase winding. Normal air-gap = 0·063 in.

losses due to eddies, hysteresis, and flux pulsations. It is these losses which are mainly affected by the eccentricity of the rotor.

The power supplied to the stator of the motor during the test was found to be practically independent of rotor eccentricity except when this reached extreme values, in which case the stator watts showed an increase of from 8 to 10 per cent. The power taken by the stator was about 830 watts for the readings at moderate eccentricities for speeds below synchronism.

An examination of the curves shown in Fig. 5 shows that at low speeds the power taken by the continuous-current motor was less with the stator of the induction motor excited than when the continuous-current motor was overcoming friction alone. This shows that the rotating field exerted an appreciable driving torque on the rotor. At synchronism this torque was reversed in direction, as shown by the sudden rise in the curve at this speed.

The same results are plotted for a constant speed as a function of the rotor eccentricity in Fig. 6. The three upper curves are for speeds above synchronism, which accounts for the gap between them and the lower ones on the same page.

The general conclusion to be drawn from the curves in Figs. 5 and 6 is that with moderate speeds of revolution and moderate values of the rotor displacement there will be no serious increase in the iron losses on account of eccentricity. In the case of the motor experimented upon, when run with the rotor winding open at normal speed and with the stator supplied at normal voltage, a displacement of the rotor amounting to 70 per cent. of the original air-gap produced an increased loss of slightly more than 25 per cent. of the total original iron losses.

Total No-load Losses of Motor.—Tests were made of the power taken by the motor when running alone unloaded and with short-circuited rotor at various eccentricities. Watts, amperes, and power factor were measured at the stator terminals for a series of values of the applied voltage and with four different values of the rotor eccentricity. These observations, like the last, were taken with the rotor winding connected successively in two different ways.

(*a*) Each phase of the rotor (consisting of two coils) was short-circuited on itself. The results are shown in Fig. 7. With these connections it was found to be impossible to run the motor at full voltage with the maximum eccentricity of 0·06 in. used in most of the tests, as the unbalanced magnetic pull was sufficient to produce rubbing between the rotor and stator cores, and the current taken by the motor was so high as to make the windings smoke. Consequently, a maximum eccentricity of 0·55 in. was employed with this arrangement of the winding.

(*b*) Each coil of the rotor winding was short-circuited on itself. The observations are plotted in Fig. 8.

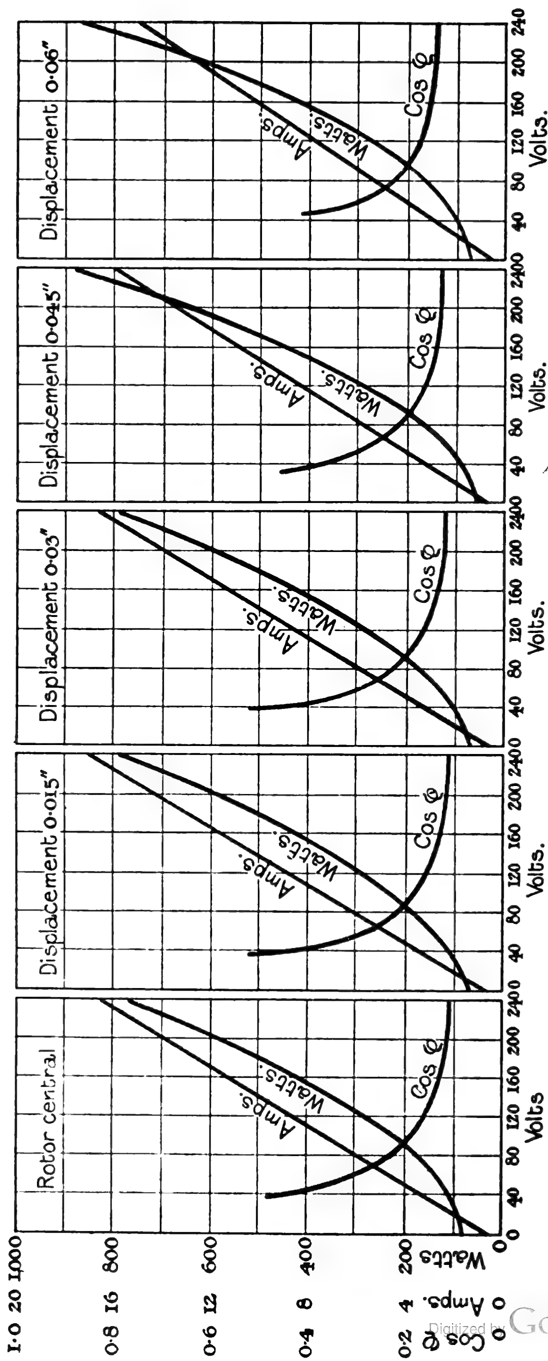


FIG. 8.—Curves of Current, Power, and Power Factor. (Motor running light.)

Multiple-circuit winding. Normal air-gap = 0·063 in.

For purposes of easy comparison the no-load losses, current, and power-factor of the motor, when running with each of the two types of winding, are plotted in Fig. 9 on a base of rotor eccentricity. The losses with the multiple-circuit winding (*b*) are seen to be smaller throughout than with the single-circuit winding (*a*), the difference becoming specially marked at high eccentricities. This superiority of the multiple winding must be ascribed to the greater power which it possesses for adapting itself to the local irregularities of the flux in the air-gap. The lower current and higher power factor of the motor with single-circuit winding are explained in the next paragraph.

In Fig. 10 are plotted the total no-load losses with normal voltage on the stator with the two types of winding and with open winding.

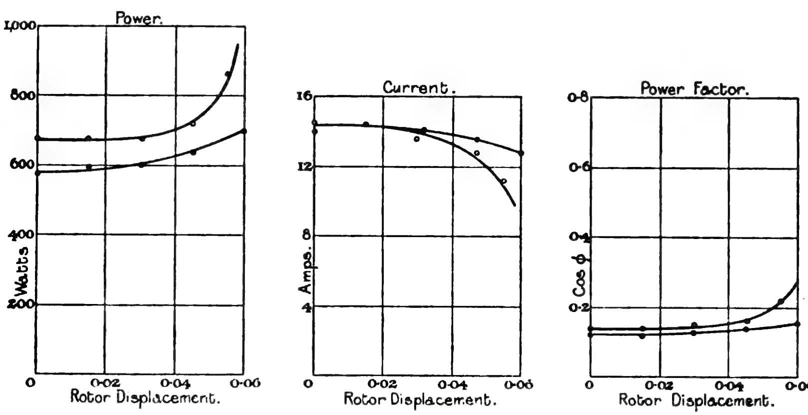


FIG. 9.—Comparison of Power taken by Motor, when Running.

Without load and with two types of rotor winding. Voltage = 200.
○ Single-circuit-per-phase winding. ● Multiple-circuit winding.

In the last case the losses were derived from the input to the continuous-current motor used for driving.

Variation of Stator Magnetising Current with Rotor Eccentricity.—The type of winding adopted for the rotor affects the value of the magnetising current taken by the stator winding when the rotor is not central (see Fig. 9).

With the type of winding in which each coil was separately short-circuited, the magnetising current was found to be practically unaffected by the rotor eccentricity. This is in accordance with the observations showing that the field is almost independent of the displacement of the rotor with this type of winding.

With the second type of winding, in which two coils of the rotor were connected in series, the magnetising current was found to be reduced by an increase in the eccentricity of the rotor. Thus, at the

normal working voltage of 200, the magnetising current fell from 14·4 to 12·7 amperes, or about 12 per cent., as the rotor was lowered from its central position by 0·055 in.

The effect here mentioned makes the power factor of a motor with an eccentric rotor appear to be higher than when the rotor is properly centred.

A rough calculation will serve to show that the change of excitation with eccentricity is to be looked for on theoretical grounds.

Let—

F = flux per pole crossing the air-gap when the rotor is central;
g = normal length of air-gap;
a = displacement of the rotor from its central position;
$k \mathrm{F} g$ = magnetising current required per pole by the 4-pole motor with central rotor.

When the rotor is eccentric, let the mean air-gap opposite to a pole

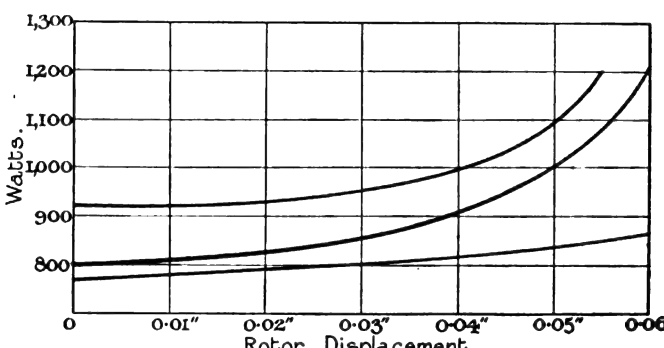


FIG. 10.—Curves of Total Losses at No Load.

Voltage = 200.
Upper curve: Single-circuit-per-phase winding.
Middle curve: Winding open-circuited.
Lowest curve: Multiple-circuit winding.

at the top of the motor become $g+y$, and the corresponding air-gap at the bottom $g-y$, where y has the value 0·9 a in the case of a 4-pole motor (*see* Appendix).

We may now suppose that the flux 2 F, which will enter the central rotor in equal portions at each North pole, will enter the eccentric rotor at the top and bottom in unequal proportions, a flux $\frac{g-y}{g}\mathrm{F}$ entering at the top of the rotor, and a flux $\frac{g+y}{g}\mathrm{F}$ entering at the bottom.

The magnetising current required for the first part of the flux will be—

$$\frac{g-y}{g} \mathrm{F}\, k(g+y) = \frac{g^2-y^2}{g} \mathrm{F}\, k,$$

while that required for the second part will be—

$$\frac{g+y}{g} \mathrm{F}\, k(g-y) = \frac{g^2-y^2}{g} \mathrm{F}\, k.$$

The value of the total magnetising current taken by the motor for both top and bottom poles will consequently undergo a change from—

$$2\, k\, \mathrm{F}\, g$$

when the rotor is central to—

$$2\, k\, \mathrm{F} \frac{g^2-y^2}{g}$$

when the rotor is eccentric.

The decrease in magnetising current is therefore proportional to the square of the rotor displacement, and increases rapidly for high values of the latter.

Magnetic Pull on Eccentric Rotor.—The value of the magnetic pull which is produced by eccentricity of the rotor and which tends to deflect the shaft, has been calculated by Rey * and by Sumec. The formula for the pull as obtained by Sumec is as follows :—

$$\mathrm{P} = \frac{\mathrm{B}^2}{8\pi} \mathrm{S} \frac{a}{g} \cdot \frac{1}{\left[1-\left(\frac{a}{g}\right)^2\right]^{\frac{3}{2}}}$$

in which the symbols have the following signification :—

P = pull on rotor due to magnetic attraction, in absolute units ;
B = mean effective induction in air-gap with concentric rotor ;
S = circumferential surface of rotor (square centimetres).
g = length of single air-gap with concentric rotor ;
a = displacement of rotor from its central position, so that $g-a$ is the smallest air-gap, and $g+a$ the largest gap.

For small eccentricities it is often sufficiently accurate to employ the simple approximate formula—

$$\mathrm{P} = \frac{\mathrm{B}^2}{8\pi} \cdot \mathrm{S} \frac{a}{g},$$

which indicates an increase in the pull on the rotor which is proportional to the eccentricity $\frac{a}{g}$.

* Rey, *Eclairage Electrique*, vol 38,. p. 281, and vol. 41, p. 257, 1904 ; Sumec, *Zeitschrift f. Electrotechnik*, vol. 22, p. 727, 1904.

Sumec's formula differs from the simpler form by the introduction of the factor—

$$\frac{1}{\left[1-\left(\frac{a}{g}\right)^2\right]^{\frac{3}{2}}}$$

which increases in value rapidly with increasing eccentricity. This factor has a value of 1·54 for an eccentricity such that $\frac{a}{g}=0\cdot5$. Sumec points out that the pull on the rotor is shown by his formula to increase to high values when the displacement is sufficient to reduce the air-gap to a small value on one side of the rotor.

Applying the formula to an actual motor, of 25-H.P., 3-phase, 2-pole, 25 cycles, 1,460 revs. per minute, the pull was found to be for—

$$\frac{a}{g}=0\cdot1, \text{ pull } 620 \text{ kg.}$$

$$\frac{a}{g}=0\cdot5, \quad ,, \quad 3{,}050 \quad ,,$$

The constants in this case were—

$$B=4{,}440, \quad S=7{,}750, \quad g=2 \text{ mm.}$$

It is to be noticed that neither Sumec nor Rey have taken into account any compensating action of the circulating currents induced in the rotor by the unbalanced field. It would appear from the results already given that this omission is fully justified in the case of motors having wound rotors of the usual single-circuit type. With a squirrel-cage or multiple-circuit rotor winding the eccentric pull would be negligibly small.

Value of Rotor Currents set up by Eccentricity.—If the rotor of a motor, in which no compensation takes place, is eccentric, the rotating field will not be constant, but will vary in strength throughout each revolution, attaining a maximum value as its axis passes the minimum air-gap. It follows that the wave-form of the voltages induced in the rotor winding will be modified in shape. Upon the main wave of rotor voltage, which has a frequency equal to the slip of the motor, there will be superposed oscillations having a frequency equal to the speed of revolution, and an amplitude depending on the amount of the eccentricity. If the type of rotor winding is such as to allow the superposed voltages to set up corresponding currents in the short-circuited winding, the virtual value of the rotor current will be altered as a result of the eccentricity, and, at the same time, the flux variations will be partly neutralised.

The superposed current oscillations which the eccentricity introduces into the rotor of a motor provided with a multiple-circuit winding may be regarded from the following point of view:—

We may imagine the axis along which the rotor is displaced to be the axis of an alternating field which is superposed upon the ordinary

rotating field which exists when the rotor is central. This superposed alternating field has the frequency, f, of the supply, and is cut by the conductors of the rotor with the frequency of rotation, n. The superposed field forms two unlike poles at opposite points of the air-gap, so that the speed of synchronism of the rotor relative to this field is f revolutions per second, or more than twice the actual working speed in the case of a 4-pole motor. Thus, except in the instance of a 2-pole motor, the slip of the motor in relation to the superposed field is always very high, and the torque resulting from this field is very small in proportion to that due to an equal flux forming part of the main rotating field.

The limiting value of the currents thus formed may be estimated in the following way :—

Let the normal stator magnetising current per pole and phase with uniform air-gap, g, be $c_0 t_1$ ampere-turns. In a 3-phase motor the ampere-turns acting along any axis of the stator would have a virtual value $\frac{3}{\sqrt{2}} c_0 t_1$.

Taking as an example the case of a 4-pole motor, a displacement, a, of the rotor will increase the reluctance of the mean air-gap of a pole on one side of the motor in the ratio $\frac{g + 0{\cdot}9\,a}{g}$, and will decrease it on the opposite side to $\frac{g - 0{\cdot}9\,a}{g}$ of its former value (see Appendix).

If we suppose that the additional balancing currents in the rotor rise to a value which is just sufficient to maintain the rotating flux at its original constant strength, they must produce a total additional magnetisation along the axis of displacement equivalent to twice $\frac{0{\cdot}9\,a}{g}\,\frac{3}{\sqrt{2}}\,c_0 t_1$, that is, to $\frac{0{\cdot}9\,a}{g}\sqrt{2}\,.\,3\,c_0 t_1$ ampere-turns.

Since this effect is due to all of the rotor coils acting in rotation, the limiting value of the extra rotor current will be $\frac{1}{3p}\,.\,\frac{t_1}{t_2}$ of the value of the stator current required to produce the same effect, where p is the number of poles of the motor, $\frac{t_1}{t_2}$ is the ratio of stator to rotor turns, and the rotor has three phases.

Hence we may write as the limiting value of the superposed rotor, currents—

$$c_e = \frac{\sqrt{2}}{p}\,.\,\frac{0{\cdot}9\,a}{g}\,c_0\,\frac{t_1}{t_2} = \frac{0{\cdot}32\,a}{g}\,c_0\,\frac{t_1}{t_2}\ \text{amperes,}$$

in the case of a 4-pole motor.

The currents thus induced will not have the same frequency as those due to the main multipolar field of the motor, since they are formed by the action of a 2-pole field. It follows that the virtual current in the rotor conductors is only increased by the amount $\sqrt{c_2^2 + c_e^2} - c_2$ amperes, where c_2 is the rotor current without eccentricity.

It follows that the additional copper losses in the rotor arising from eccentricity cannot increase the total rotor copper losses in a greater ratio than—

$$\frac{c_2^2 + \left(0{\cdot}32 \frac{a}{g} c_0 \frac{l_1}{l_2}\right)^2}{c_2^2}.$$

It is evident that this cannot represent a serious increase in the normal rotor copper losses under load, unless the rotor displacement reaches a value which makes the air-gap dangerously small.

In a paper * suggesting the subdivision of the end-rings of a squirrel-cage motor, Osnos states that large and injurious compensating currents may arise in the rotor due to its eccentricity, but he does not give any calculation of the value which they may reach.

Oscillograph Records of Rotor Voltage.—By the use of special temporary slip-rings fixed on the motor, it was made possible to trace the wave-form of the voltages induced in search coils which were wound in the slots of the rotor.

In the oscillograph curves obtained in this way there are three main types of variations to be distinguished :—

1. Voltage variation due to the passage of the search coil across the flux forming the main rotating field, having a periodicity equal to the slip of the motor.
2. Pulsations of voltage of high frequency arising from the irregularities in the flux set up by the teeth.
3. Variations of voltage caused by the inequality of the air-gap when the rotor of the motor is eccentric. The frequency of this voltage is that of the speed of rotation of the rotor, while its amplitude is dependent on the displacement given to the rotor.

These three types of variation are easily distinguishable in most of the curves which are reproduced. For example, in Fig. 19 there is shown rather more than one complete cycle of voltage variation due to slip, which includes 18 cycles of variation due to rotor eccentricity and indications of a large number of higher-frequency pulsations due to the teeth.

In Figs. 11 to 14 are shown the curves obtained by connecting the oscillograph to a search coil wound round a single tooth of the rotor core. Normal voltage was applied to the stator, and the motor ran without load, with the rotor winding short-circuited to give one circuit per phase. The slip of the motor was very small (less than 1 per cent.). The record was taken in each case at the time when a hot-wire voltmeter connected to the search coil indicated that the voltage due to slip was passing through its maximum value. This voltage remained constant for practical purposes during the brief period required for taking the record. The search coil was thus travelling almost synchro-

* *Zeitschrift f. Elektrotechnik* (Wien), vol 20, p. 389, 1902.

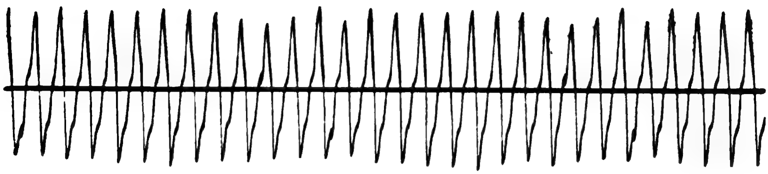


FIG. 11.

Rotor central. Virtual volts = 2·4.
Motor unloaded. Search coil on one tooth.

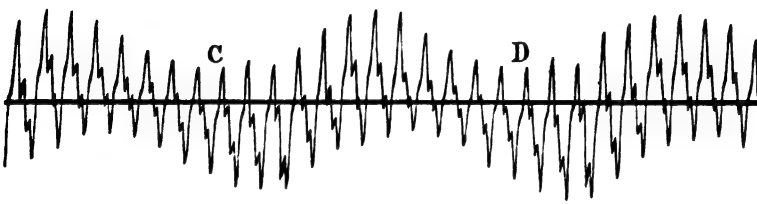


FIG. 12.

Rotor displaced = 0·03 in. Virtual volts = 2·64.
Motor unloaded. Search coil on one tooth.

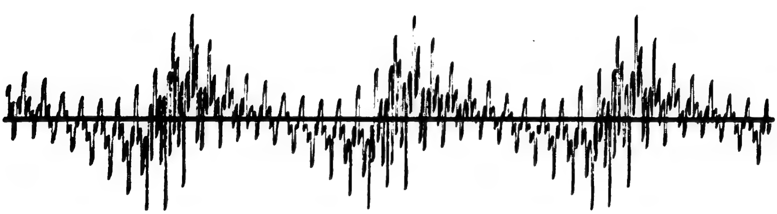


FIG. 13.

Rotor displaced = 0·04 in. Virtual volts = 4·2.
Motor unloaded. Search coil on one tooth.

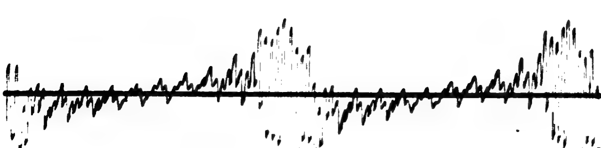


FIG. 14.

Rotor displacement = 0·055 in. Virtual volts = 5·0.
Motor unloaded. Search coil on one tooth.

nously with the main field, and was situated in its densest part at the time of the observation. These curves exhibit no variation due to slip; the principal wave in the curve 12 is due to eccentricity.

In Fig. 11 the rotor was central, and the oscillations indicated on the curve are due to tooth pulsations. These oscillations are seen to correspond closely with those of the curves drawn in Fig. 3 from obser-

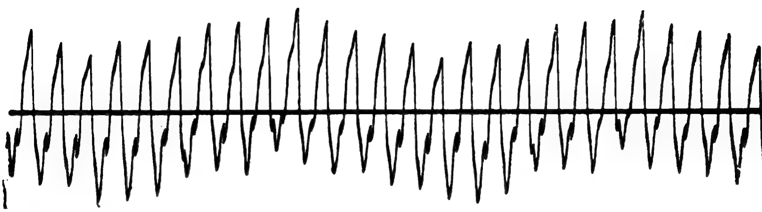


Fig. 15.

Rotor slightly displaced. Virtual volts = 1·3.
Motor unloaded. Search coil embracing one pole-pitch.

vations made on the stationary motor. In taking Figs. 12 to 14 the rotor was adjusted eccentrically. The increasing amplitude of the flux variation produced by the greater eccentricity of the rotor is clearly shown, also the greatly increased amplitude of the tooth pulsations at the point of minimum air-gap. The flux in the dense field is highly concentrated in the teeth, and leaps from tooth to tooth with great suddenness.

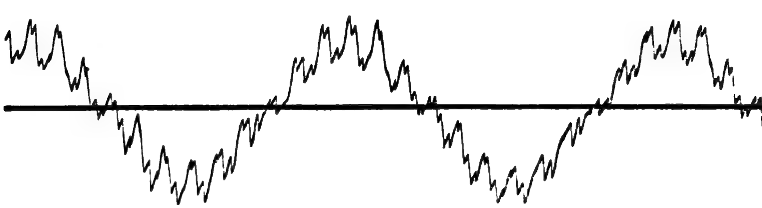


Fig. 16.

Rotor displaced = 0·03 in. Virtual volts = 2·1.
Motor unloaded. Search coil embracing one pole-pitch.

The scales of the various curves are not identical, but the virtual voltage represented by each is given below it.

In Figs. 15 to 17 are shown curves taken under exactly the same conditions of working, but with a different search coil. The search coil used in this case was wound so as to embrace one-quarter of the rotor circumference (one pole-pitch), so that the records indicate variations of the flux per pole.

In all of these curves the principal wave, due to eccentricity, has a frequency equal to the number of revolutions per second of the motor.

Figs. 18 and 19 show curves taken with the object of illustrating the wave-form of the voltage induced in the rotor winding under working

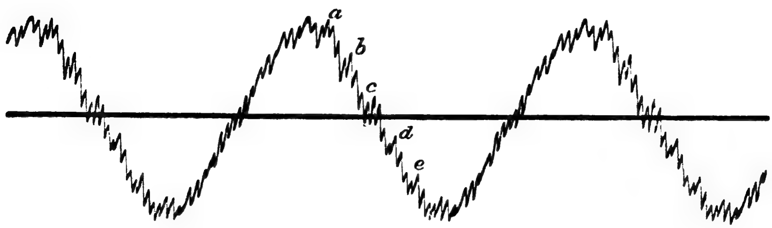


FIG. 17.

Rotor displaced = 0·055 in. Virtual volts = 7·8.
Motor unloaded. Search coil embracing one pole-pitch.

conditions. The search coil used for these curves was wound in the same slots as one complete coil of the rotor (3 slots per side).

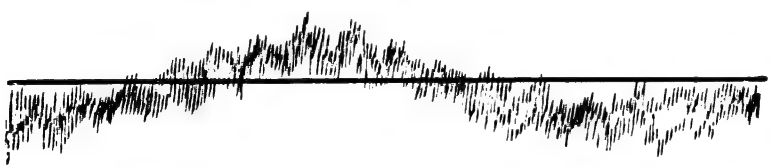


FIG. 18.

Rotor central. Virtual volts = 0·75
Motor loaded. Search coil in same slots as rotor winding.

The motor was heavily loaded so as to increase the slip. The two curves represent the voltages in the rotor with no eccentricity and with

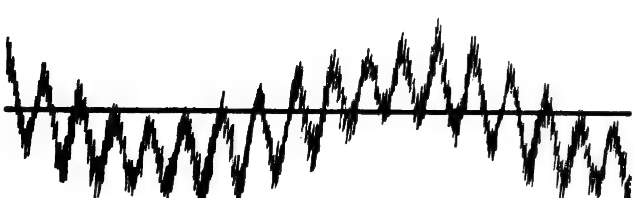


FIG. 19.

Rotor displaced = 0·018 in. Virtual volts = 0·75.
Motor loaded. Search coil in same slots as rotor winding.

a small displacement of the rotor, such as might be found in a very large proportion of the motors in actual service. The horizontal scale of Figs. 18 and 19 is very much smaller than that of the previous curves.

Oscillograms taken on the rotating motor with open-circuited rotor winding were practically identical with those already given, except for a slight difference in the amplitude of the tooth pulsations.

Summary and Conclusions.—A displacement of the rotor of an induction motor from its central position results in a change of the flux density along the axis of displacement, which is approximately proportional to the change in the magnetic permeance of the air-gap, when the rotor is open-circuited. A closed rotor winding having a single circuit per phase hardly alters this distribution of flux at all. A multiple-circuit winding on the rotor becomes the seat of balancing currents which are sufficient to maintain an almost uniform mean flux round the air-gap, irrespective of rotor displacement. The balancing currents are strictly limited in value, and are not great enough to produce any serious increase in the rotor copper losses with moderate displacements of the rotor. The asymmetry of the field due to rotor eccentricity, when not compensated by rotor currents, gives rise to an additional iron loss, which increases uniformly with small eccentricities. With larger eccentricities these losses increase rapidly. Increased eccentricity is also attended by less favourable starting of the motor, and by a diminished magnetising current. The unbalanced magnetic pull on the eccentric rotor increases, at first slowly, but afterwards at a higher rate, with increase of eccentricity. With a multiple-circuit rotor winding no appreciable iron loss or unbalanced magnetic pull is produced even by extreme values of the eccentricity. The total effect of rotor eccentricity on the losses of the motor was found to be very small for all displacements, when the multiple-circuit type of winding was used; with the single-circuit-per-phase winding, the increase in losses was more marked, but did not become important for eccentricities less than 20 or 25 per cent. of the length of the original air-gap.

The authors desire to make acknowledgment to the Committee and Principal of the Municipal School of Technology, Manchester, for the facilities afforded them for carrying out the experiments described in this paper.

APPENDIX.

Value of Mean Length of Polar Air-gap.—It is desired to find the mean length of air-gap at the top and bottom of a motor in which the rotor has sunk from its central position.

In order to make the calculation directly applicable to the motor used in the experiments, it will be convenient to consider a 4-pole motor, and to find the mean air-gap subtended by one pole-pitch ($\frac{1}{4}$ of the rotor circumference) at the top and bottom of the motor.

Let—

R = radius of stator bore ;
r = outside radius of rotor ;
a = distance through which rotor has sunk ;
x = length of air-gap, as measured from centre of stator, along a radius making an angle θ with the vertical axis.

It follows geometrically that—

$$r^2 = (R - x)^2 + a^2 - 2\,a\,(R - x)\cos\theta$$

$$= R^2 - 2\,Rx + x^2 + a^2 - 2\,a\,(R - x)\cos\theta$$

or neglecting x^2, a^2 and $2\,a\,x\cos\theta$ in comparison with other terms,

$$r^2 = R^2 - 2\,Rx - 2\,a\,R\,.\cos\theta$$

whence—

$$x = \frac{R^2 - r^2 - 2\,a\,R\cos\theta}{2\,R}$$

Mean value of x over one quadrant—

$$= \frac{2}{\pi}\int_{-\frac{\pi}{4}}^{\frac{\pi}{4}}\left(\frac{R^2 - r^2}{2R} - a\cos\theta\right)d\theta$$

$$= \frac{R^2 - r^2}{2\,R} - \frac{2\,a}{\pi}\,2\sin\frac{\pi}{4}$$

$$= \frac{R^2 - r^2}{2\,R} - \frac{2\sqrt{2}\,a}{\pi}$$

Writing $R - r = g$, the length of the original air-gap, the mean value obtained above becomes by a further approximation—

$$g - 0{\cdot}9\,a.$$

It is evident that, in the case of a motor with a greater number of poles, the mean value of the air-gap for the arc subtended by one pole-pitch would approximate still more nearly to the value $g - a$ at the part of smallest air-gap.

AN INDICATING COIL FOR APPLYING THE OSCILLOGRAPH TO THE STUDY OF COMMUTATION.

By DAVID ROBERTSON, B.Sc., Associate Member.

(*Paper received 1st January*, 1912.)

CONTENTS.

SUMMARY.

After describing the methods already in use, the author explains a way in which the oscillograph can be applied to show the internal currents in an armature without cutting one of the main coils. Records are given illustrating various points about commutation to illustrate his method, and improvements in details are discussed. He also urges the insertion of the indicating coil during construction as a matter of course in all large machines, or others working near the limits of good commutation.

INTRODUCTION.

The chief uses to which the oscillograph can be put in connection with commutating machines are the investigation of* :—

* See for instance :—

(*a*) and (*c*). D. K. Morris and J. K. Catterson-Smith, "Some Uses of the Oscillograph," *Journal of the Institution of Electrical Engineers*, vol. 33, p. 1019, 1904.

(*a*). J. K. Catterson-Smith, "Commutation in a Four-pole Motor," ibid., vol. 35, p. 430, 1905.

(*b*) and (*c*). F. G. Baily and W. S. H. Cleghorne, "Some Phenomena of Commutation," ibid., vol. 38, p. 150, 1906.

(*d*). G. W. Worrall, "Commutation Phenomena and Magnetic Oscillations occurring in a Direct-current Machine," ibid., vol. 45, p. 480, 1910.

(*a*) The change of current in an armature coil during commutation.
(*b*) The voltage between the brush and segment at the moment of parting.
(*c*) The changes of flux distribution produced by armature reaction.
(*d*) The oscillations of flux produced in the various parts of the machine while it is working.

The usual way of studying commutation by its aid is to cut one of the armature coils and connect the free ends to slip-rings from which the current is led to the oscillograph shunt, but there are several objections to this method. In the first place, the arrangement is not one which any dynamo builder would contemplate with equanimity for a large machine, or indeed for any except a purely experimental machine. A break in the external connections to these slip-rings would open one of the armature paths and cause violent sparking at the brushes, to say nothing of possible heavy unbalanced forces. This danger can be avoided by fixing the shunt on the armature itself, and so leaving only the oscillograph current to be carried by the rings.* The resistance and heating of this shunt would be objectionable, and provision would probably be necessary for short-circuiting it except when experimental runs are being made.

But another, and still greater, disadvantage remains. The resistance of a single coil of the armature is quite small, and consequently the addition of a shunt, which would probably have a resistance several times as great as that of the coil, makes the conditions very different from those of normal running, and correspondingly reduces the value of the results obtained. Such added resistance would, for example, greatly diminish the short-circuit currents caused by the brushes being displaced from the neutral-point, or by their being too wide, while it would also make the brush contact resistance less effective in straightening out the current curve.

Indicating Coil.

If we go yet another step and make the armature coil act as the shunt, we shall entirely get rid of the defects just discussed, but we are then met with the difficulty that there are motion and inductance (both self and mutual) E.M.F.'s in this coil as well as the resistance E.M.F. In 1904 the author devised a method of compensating for these E.M.F.'s and had the arrangement fitted to a machine belonging to the Merchant Venturers' Technical College, Bristol, whose armature was then being altered. However, not having an oscillograph at the time, and later having a large amount of extra work owing to the fire at the college in 1906, the author had no opportunity of trying the coil until 1907, since which time it has been regularly used for class demonstrations. In

* E. Arnold has used this arrangement. See his "Die Gleichstrommaschine," p. 784. (Berlin, J. Springer, 1906.)

principle it is exactly the same as the device applied later by Mr. Campbell* to produce non-inductive shunts for alternating-current work. A special coil of thin wire is wound as closely as possible to one of the armature coils with the same number of turns and connected to the same segments of the commutator. The back of this auxiliary coil, which may be termed an "indicating coil," is cut and connected to slip-rings, and it forms the leads connecting the armature coil, acting as a shunt, to the oscillograph. The arrangement is shown in Fig. 1 as applied to a lap-winding; with a multipolar wave-winding, as in the actual machine already mentioned, the segments at the two ends of the coil are not adjacent, but are separated by about two pole-pitches. Space can generally be found for the indicating coil without altering the slot dimensions, and the Duddell oscillograph only requires about

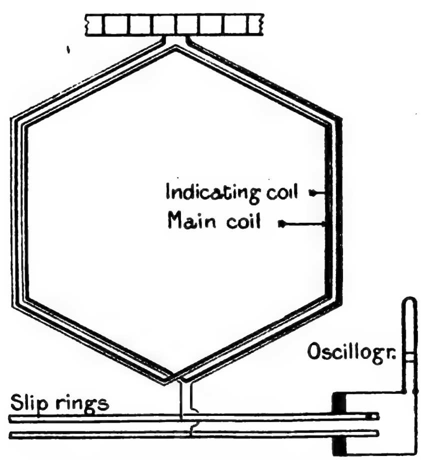


FIG. 1.—Connections of Indicating Coil to Oscillograph.

$\frac{1}{10}$ ampere at most. Consequently, even with a small machine, it makes no appreciable difference to the main coil whether the indicating rings are in use or not.

The difference of potential between the two segments is the sum of all the E.M.F.'s in any path by which we can go from one to the other. Applying this to the two coils we get:—

$$E_{R_1} + E_{M_1} + E_{L_1} = V = E_{R_2} + E_{M_2} + E_{L_2},$$

where the three E.M.F.'s are respectively the resistance, motion, and inductance E.M.F.'s, and the 1 refers to the main coil and the 2 to the other with its external circuit. But, from the construction adopted—

$$E_{M_1} = E_{M_2} \quad \text{and} \quad E_{L_1} = E_{L_2}.$$

* A. Campbell, "Compensation of Self-induction in Shunt Resistances," *Electrician*, vol. 61, p. 1000, 1908.

Consequently—

$$E_{R_1} = E_{R_2} \quad \text{or} \quad R_1 I_1 = R_2 I_2,$$

or—

$$I_1 = \frac{R_2}{R_1} I_2.$$

That is to say, the ordinary laws of shunts apply and the oscillograph current is a definite fraction of the total current in one armature circuit.

The compensation of the motion and induced E.M.F.'s could only be absolutely perfect if the two coils were completely coincident, which is, of course, impossible. The two coils are wound side by side in the original armature, and the motion E.M.F. is very well balanced except at the places where the indicating coil is close to the edges of the poles. The bottom curves of Fig. 4, taken with the fields separately excited and the brushes lifted, show little humps at these positions denoting an imperfect balance there, and Fig. 2 shows why it occurs. At the edges of the poles the flux density varies rapidly with the position and therefore the conductor nearest the pole has a greater E.M.F. induced in it

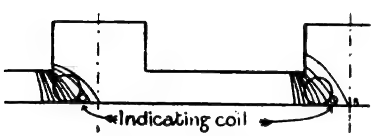


FIG. 2.—Unequal Action in the two Coils.

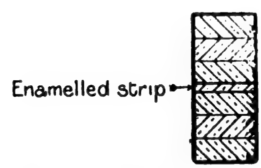


FIG. 3.—Arrangement of Indicating Lead in Rectangular Conductor.

than one just beyond it. If further, as in this case, the indicating coil is entirely to one side of the main coil (and not as in Fig. 1), then the E.M.F.'s in the two coils will be different and will produce a circulating current. If the matter be closely examined it will be seen that the opposite signs of the humps at the two edges of the same pole and the similar signs of those at the adjacent edges of different poles agree with this explanation. The other alternative is that these humps represent currents circulating between the two armature circuits, but in that event we should expect similar humps to be produced by all the other coils besides the one being indicated, in which case the rest of the curve would be rippled instead of straight.

Ripples are shown opposite the poles on several of the other curves on the same figure, and occasionally these ripples were seen to spring away from the zero-line and remain away for several seconds. The ripples are caused by the flux oscillations produced by the large short-circuit currents occurring in the other coils which are short-circuited by the brushes when out of the neutral zone. They *may* be actual circulating currents due to the unequal induction in the two parallel

circuits of the armature, since the number of coils in each circuit varies with the phase of commutation, but it is more probable that they are also due to imperfect compensation of the indicating coil. The deviation from the zero-line seems to be caused by comparatively slow changes in the field current caused by a variation of the supply voltage. The flux oscillations are themselves very well shown in Fig. 12.

No opportunity has yet occurred of winding an indicating coil in another machine, but it is hoped to have one shortly. It is proposed to improve the arrangement by getting the two coils much closer together. For small machines with round wire the following two methods suggest themselves. The main conductor of the coil to be indicated could be made of stranded wire, of which one of the outer strands has been enamelled to insulate it from the rest. This strand would form the indicating coil, and be cut and connected to the slip-rings in the way already described. It is probable that the lay of the strand would give practically perfect compensation. Another way would be to wind a layer of enamelled foil spirally round the main conductor to form the special coil. Very little insulation is required between the main and indicating coils, for the maximum potential difference between them is well under 1 volt, and a breakdown of that insulation would have no more serious effect than to reduce the current sent through the instrument. For larger machines using rectangular wire the indicating lead could easily take the form of an enamelled strip placed between the laminations of the main conductor near the centre of its section, as shown in Fig. 3.

Examples of the Use of the Indicating Coil.

A number of oscillograms are given in Figs. 4–11, more to illustrate the uses of the coil than as a contribution to the theory of commutation, a study of which it is hoped to carry out later with the aid of an improved coil. Being drawn by hand on the tracing desk of a Duddell high-frequency outfit, much of the smaller detail has become inaccurate or has been lost altogether. But in any case, no print, however good, can show the life of the curves as they actually appear on the screen. To see the changes actually taking place, knowing at the same time what is happening to the machine, is most instructive, while the snake-like behaviour of the lines when the load hunts is quite fascinating.

Before taking the oscillograms, with the exception of Figs. 8 and 9 which are older ones, the spacing of the brushes was carefully adjusted and the brush faces freshly ground and the commutator polished. The brush-holders now on the machine are of the lever type, which causes the carbons to bear only on the forward edges after regrinding owing to the angle turned through to make up for the thickness of the emery cloth. Although the machine had been run for several days before taking the records, the brushes had not worn down so as to bear over their whole surface by the time of the experiment, and the negative ones, particularly No. 1, happen to have been better than the positives—

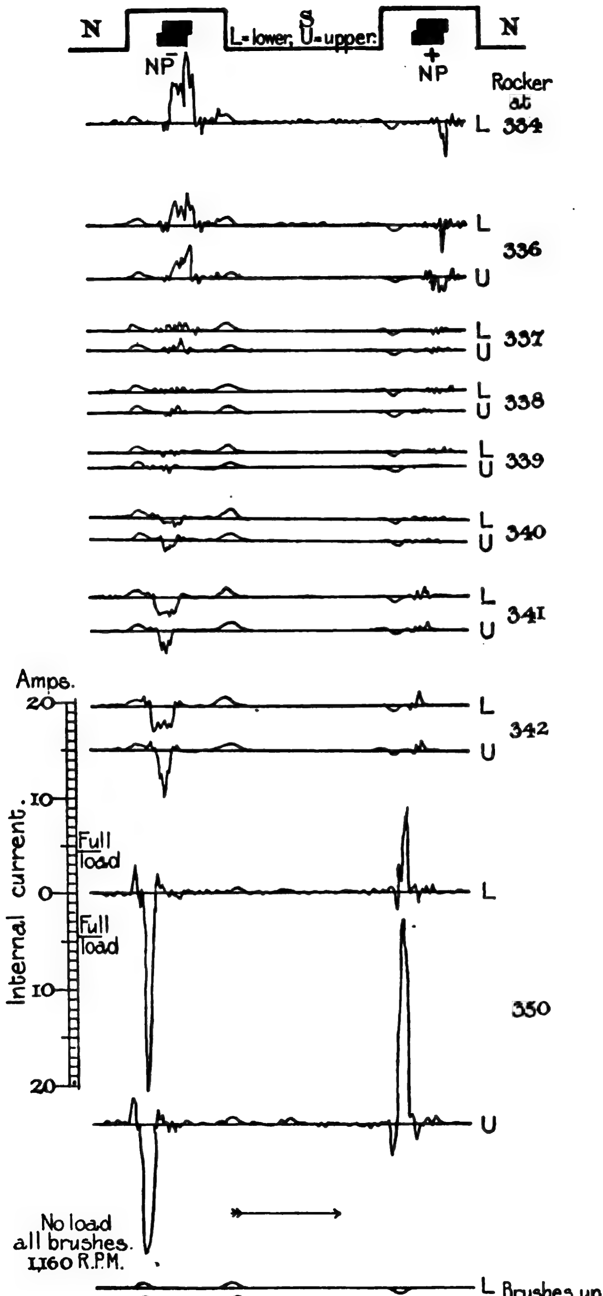


FIG. 4.—Short-circuit Currents at No Load with different Brush Positions.

that being called positive by which the motoring current enters the armature. The positions of the poles are shown on the diagrams, and to these are added the position which the short circuits would have if the brushes had made contact over their whole width. The overlap of the short circuits by the two brushes of the same polarity is typical of a wave winding and is reversed at the other two poles. The names marked on the poles correspond to the position of the left-hand side (lower layer) of the coil indicated.

Fig. 4 shows the effect of displacing the brushes from the neutral-point when there is no load on the armature, curves being given in most cases for both poles of the same name. When tested after the run by the zero mutual inductance method, the neutral position of the brushes came to 340 on the rocker scale, but the oscillograms indicate a different position, and also show a difference between the positive

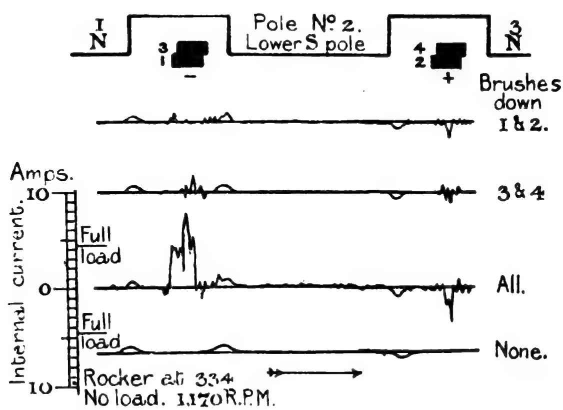


FIG. 5.—Effect of Lifting one Brush on No-load Short-circuit Currents.

and negative brushes due to imperfect bedding. With the rocker at 350 the short circuits take place near the edges of the poles, and currents many times full-load current then circulate in the coil. It is these heavy short-circuit currents which produce the very marked oscillations shown in the flux curves of Fig. 12. These high peaks are always a bit unsteady, but less so than might have been expected. There was some sparking with the brushes so far back, but not enough to be serious. The ripples opposite the poles have already been discussed in connection with the faulty compensation of the indicating coil.

Fig. 5 shows the difference between having all the brushes in use and only one of each pole, but this figure would have been more satisfactory if the brushes had been properly bedded in. Fig. 9 shows the difference between the brushes better, it being exaggerated by the unequal spacing.

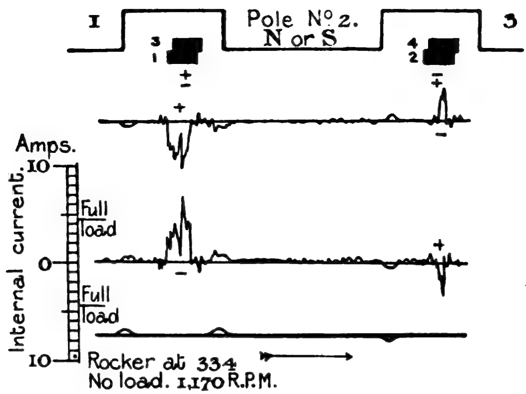


FIG. 6.—No-load Short-circuit Currents with Reversed Magnets

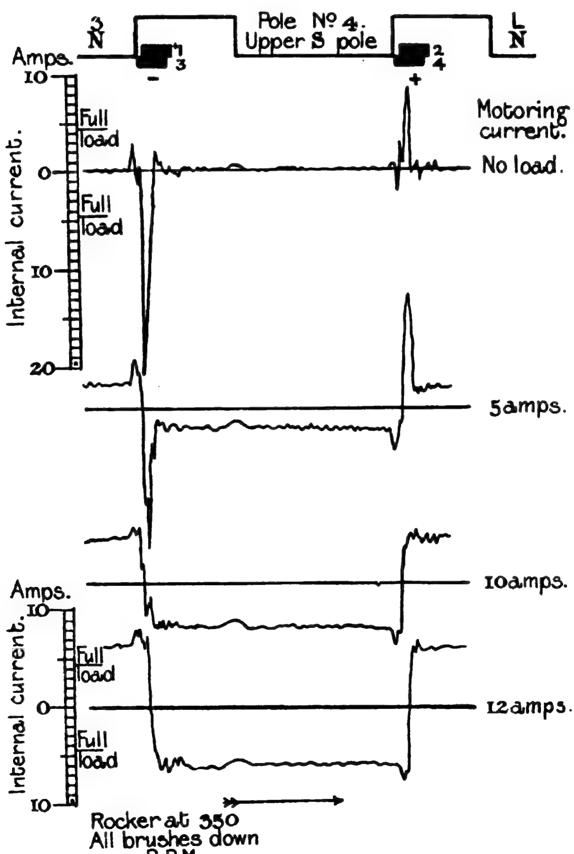


FIG. 7.—Internal Currents with different Loads and constant Brush Position.

For Fig. 6 the polarity of the magnets was reversed between the two records, but the machine was not run for any considerable time with the reversed polarity. The differences between the two curves are too small to say that they are caused by other than change with time and error of tracing.

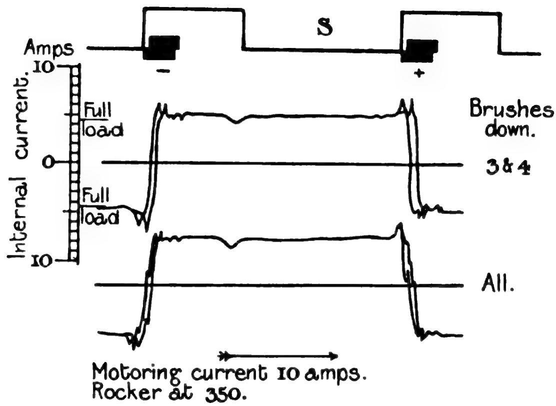


FIG. 8.—Comparison of different Poles of same Name. (Brushes incorrectly spaced).

The effect of changing the load without altering the brushes is shown in Fig. 7; the way in which the short-circuit peaks draw in as the load is increased should be noted. These oscillograms show that the brushes now employed are too wide even for the current of 12 amperes (30 per cent. overload), for although the lead is such as to cause very large

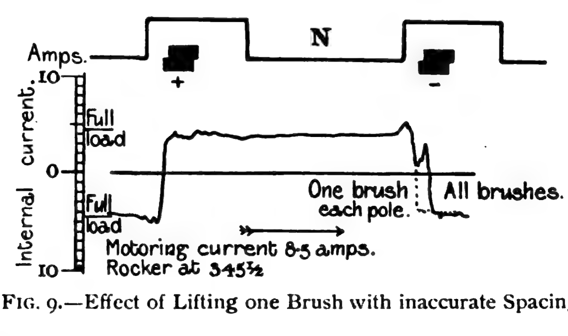


FIG. 9.—Effect of Lifting one Brush with inaccurate Spacing.

short-circuit currents at no load, and considerably to over-reverse the smaller currents, it is still insufficient to prevent the large currents increasing at the commencement of the short circuit.

Fig. 8 shows the two poles of the same sign overlapping, the brushes being inaccurately spaced. It also shows the effect of lifting one of the

brushes. Fig. 9 shows a large brush error. Figs. 10 and 11 show combined alternating-current and direct-current loads, but as the machine was coupled to the others, the ratio of the two is not the same as if it had been running as a rotary converter.

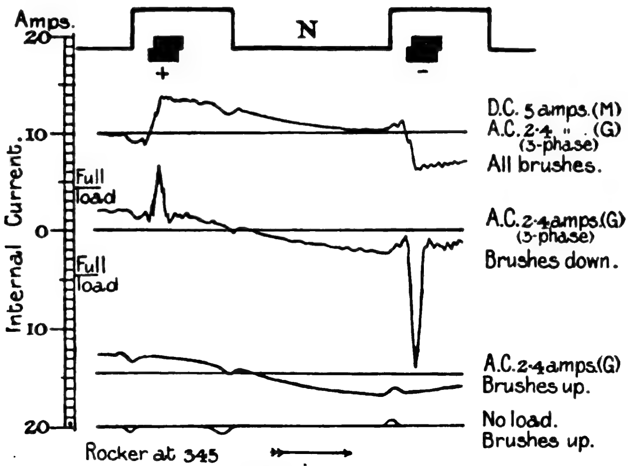


FIG. 10.—Combined Alternating-current (Generator) and Direct-current (Motor) Loads.
(Indicated Coil near Tapping.) (2 Coils and 40 Coils between Indicated Coil and adjacent Tappings.)

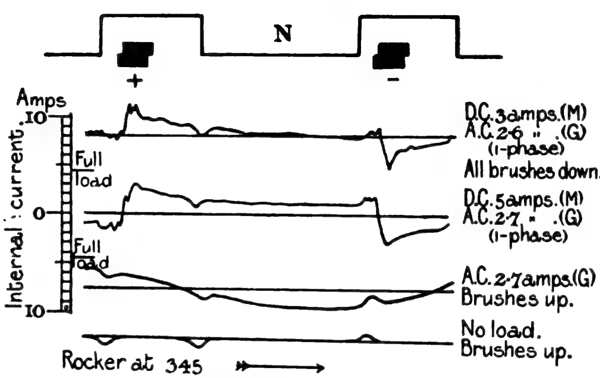


FIG. 11.—Combined Alternating-current (Generator) and Direct-current (Motor) Loads.
(Indicated Coil remote from Tapping.) (23 Coils and 40 Coils between Indicated Coil and adjacent Tappings.)

Fig. 12 gives the E.M.F. wave for a coil wound ring-fashion in a ventilating hole and the bottom of a slot, and shows the distribution of the flux opposite the poles combined with the effect of the change

of total flux with the magnetic oscillations. The bottom curve was taken with the brushes up; the ripples in it are due to the armature teeth. The splashes on the middle one are due to the short-circuit currents shown at 350 on Fig. 4, while the top curve displays the armature reaction with a load of 15 amperes (70 per cent. overload).

It is interesting to note that if both ends of the indicating coil be connected to the same segment so as to short-circuit it in front, the curve on the screen would be the flux curve. Provision for changing the connections so that one coil could be used for either would, however, be a source of danger, and so it is better to have a separate coil, especially as the other would only give the mean flux density at slightly different places on two adjacent poles. The flux curve can be obtained very approximately without any permanent arrangements on the arma-

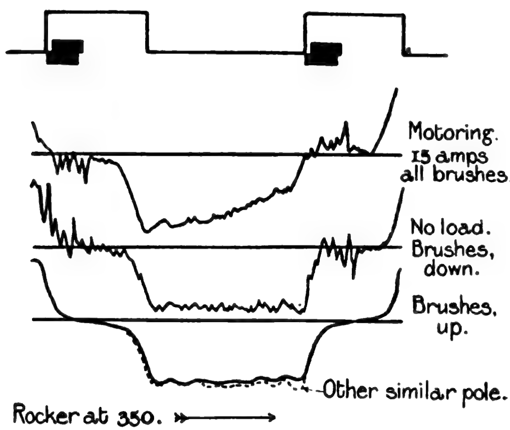


Fig. 12.—Flux Distribution Curves, showing Effect of Armature Reaction and of Short-circuit Currents.

ture if two slip-rings be placed over the commutator and connected to the two segments at the end of one coil.

Description of the Experiments.

The machine used in these experiments is a special experimental one, by Mavor and Coulson, having 4 poles and rated at 5 H.P., 500 volts, and 1,200 revs. per minute. There are 129 segments and the same number of coils of six turns each, and 43 slots. The winding is the 2-circuit wave-winding usual for that size of machine. The coils span 10 teeth and 64 segments, the pole-pitch being $10\frac{3}{4}$ tooth-pitches, and the pole-span 6·6 tooth-pitches. The commutator is 7 in. in diameter, and the brushes $\frac{5}{8}$ in. wide; the pitch of the segments is thus 170 mils or 2·8°, while the brush-span is 3·7 segments or 10°. A number of machines stand in line and can be coupled together as required, while a public

supply from the city mains of direct-current at 250 or 500 volts, and of alternating-current at 105 or 210 volts and 93 cycles per second, is available. The power was circulated between two machines on the 500-volt mains, or between the latter and the alternating-current mains, the former giving a much steadier load. A resistance was always left in circuit with the armature of the machine tested so as to throw most of the fluctuations due to change of voltage on the other machine. One of the alternators in the line of machines supplied the current for the oscillograph motor; it has 8 poles, and so the time-scale was drawn out to twice what it would have been if the oscillograph mirror had been driven from the alternating-current slip-rings with which the direct-current machine is provided; there were also the additional advantages that the machine being tested did not have to carry the current for this little motor, and that the portion of the curve on the screen could be adjusted by swinging the stator of the alternator, which is mounted on ball-bearings. The double time-scale causes the curves for two similar poles to overlap; as was shown in Fig. 8 these do not quite coincide. They were separated by the very simple dodge of covering half the circumference of the indicating rings with paper. This was originally tried as a temporary expedient in the hope that the paper would last long enough to allow the curves to be identified, but quite unexpectedly it ran for many hours without renewal. The position of cut-off could be adjusted by moving the rocker on which the indicating brushes were carried, and it also gave an index by which the position of the machine corresponding to any point on the curve could be roughly determined.

For a complete study of commutation it is desirable still further to increase the time base. It can be made about three times as great, giving a total magnification of six, by using the return stroke of the cam; a special shutter is then desirable to cut the light off for three-fourths instead of the usual one-fourth of each revolution of the oscillograph motor. In further work it is proposed to employ a rotating mirror, as this will give a more certain time-scale than a quick-running cam. The objection to a rotating mirror for ordinary work is that too much light is lost owing to the fact that it is only reflected up to the screen during a small fraction (about $\frac{1}{12}$) of each revolution, which means that the spot of light will pass over the same spot every twelfth cycle or so instead of every other. But this is an advantage for our purpose, for when the speed of the motor is increased so that it goes round once a cycle, as was the case for the oscillograms given in the paper, the part of the cycle which is lost is not wanted and we only get a small portion on the screen at a time.

Practical Applications.

The uses of the indicating coil for teaching purposes are fairly obvious, but the author is of opinion that it is even more valuable to the manufacturer of large machines, and he strongly urges that it should be fitted as a matter of course to all important machines

while they are being built, just as an engine-builder always provides indicator cocks on his engine. The indicating coil should be of special service on turbo-dynamos, and on all machines which have to be worked near the limits of satisfactory commutation, and it should give much useful information as to the actions taking place in alternating-current commutating machines. The extra cost of the arrangement is small, being little more than that of providing the two slip-rings, which need only be large enough for strength. It is not necessary to provide alternating-current tappings for the oscillograph motor; a direct-current motor would be even better as the gradual slip taking place when the speed is as nearly right as can be got brings the different parts of the curve into view in turn, while records can always be obtained with the falling plate or other photographic arrangement. The indicating coil would give invaluable information while making the adjustments of the brushes, commutating poles, and so forth, and quickly lead to the best arrangements for these parts being settled.

There are very few, if any, machines in which the resistance of a single coil is too low to give a sufficient deflection of the oscillograph when used in this way. Each coil of the machine already referred to consists of 14 ft. of 18 S.W.G. wire; consequently the current density at full load is 2,500 amperes per square inch, and the product of length and current density, upon which the voltage available for the oscillograph depends, is 420,000 amperes per inch or 16,600 amperes per millimetre. With the oscillograph fuses cut out this gives an ample sensibility of 2·5 mm. per ampere in the main coil. This product is limited by cost on the one hand and by commutating considerations on the other, and its value does not differ very greatly for machines of different size, and it is seldom less than half the amount just given.

Conclusion.

In conclusion, the author wishes to express his thanks to Mr. G. W. P. Page for his valuable assistance in carrying out the experiments and in making the records; to the Governors of the Merchant Venturers' Technical College for the use of the college equipment, and to the Bristol University Colston Society for a grant to enable the work to be carried further.

ANNUAL DINNER, 1912.

The annual dinner of the Institution was held in the Grand Hall of the Hotel Cecil on Thursday, 1st February, 1912. The President, Mr. S. Z. de Ferranti, presided at a gathering numbering about 350 persons. Among those present were: The Right Hon. Sir G. H. Reid, P.C., G.C.M.G. (High Commissioner for the Commonwealth of Australia), the Right Hon. Lord Alverstone, G.C.M.G. (Lord Chief Justice), Mr. Alexander Siemens (Past President), Professor S. P. Thompson, F.R.S. (Past President), the Right Hon. Lord Justice Buckley (Lord of Appeal), the Right Hon. Lord Justice Fletcher Moulton, F.R.S. (Lord of Appeal), the Hon. Mr. Justice Parker, Mr. W. M. Mordey (Past President), Professor John Perry, F.R.S. (Past President), Professor W. C. Unwin, F.R.S. (President of the Institution of Civil Engineers), Sir James Crichton-Browne, F.R.S. (Treasurer of the Royal Institution), Mr. E. White (Chairman of the London County Council), Sir R. Hunter, K.C.B. (Solicitor to the General Post Office), Mr. R. Hammond (Hon. Treasurer), Sir T. Barlow, Bart., K.C.V.O. (President of the Royal College of Physicians), Sir B. A. Whitelegge, K.C.B. (Chief Inspector of Factories, Home Office), the Hon. Sir N. J. Moore, K.C.M.G. (Agent-General for Western Australia), Mr. W. Duddell, F.R.S. (Vice-President), Mr. W. Judd (Member of Council), Sir Wm. Ramsay, K.C.B., F.R.S. (President of the British Association), Sir Alfred Keogh, K.C.B. (Rector of the Imperial College of Science and Technology), Sir Norman Lockyer, K.C.B., F.R.S. (Director of the Solar Physics Observatory), Sir Horace Monro, K.C.B. (Permanent Secretary, the Local Government Board), Sir A. King, K.C.B. (Secretary of the General Post Office), Mr. Hugo Hirst (Member of Council), Mr. J. F. C. Snell (Vice-President), Sir Laurence Gomme (Clerk to the London County Council), Mr. J. S. Highfield (Member of Council), Mr. C. H. Wordingham (Member of Council), Mr. R. J. Godlee (President, Royal College of Surgeons), Sir Philip Magnus, M.P. (Secretary of the Department of Technology, City and Guilds of London Institute), Sir H. F. Donaldson, K.C.B. (Superintendent of Woolwich Arsenal), Mr. W. W. Cook (Member of Council), Mr. R. K. Morcom (Member of Council), Sir H. Trueman Wood (Secretary of the Royal Society of Arts), Sir J. Larmor, F.R.S. (Secretary of the Royal Society), Mr. J. E. Kingsbury (Member of Council), Mr. W. M. Morrison (Member of Council), Mr. C. P. Sparks (Member of Council), Mr. B. M. Jenkin (Member of Council), Sir A. B. Kempe, F.R.S. (Treasurer of the Royal Society), the Hon. J. D. Fitzgerald, K.C., Mr. S. Morse (Member of Council), Mr. E. Russell Clarke (Member of Council), the President of the Elektrotechnischer

Verein, Mr. H. E. Haward (Comptroller of the London County Council), the Hon. A. A. Kirkpatrick (Agent-General for South Australia), Mr. E. B. Ellington (President of the Institution of Mechanical Engineers), Mr. W. F. Marwood, C.B. (Railway Department, the Board of Trade), Mr. H. E. Wimperis (Member of Council), Mr. W. Cramp (Chairman of the Manchester Local Section), Professor H. L. Callendar, F.R.S. (President of the Physical Society), Dr. W. N. Shaw, F.R.S. (Director of the Meteorological Office), Dr. R. Messel (President of the Society of Chemical Industry), Mr. M. J. Railing (Chairman of the Birmingham Local Section), Professor J. J. Dobbie, F.R.S. (Principal of the Government Laboratories), Mr. T. G. White (Secretary of the New South Wales Government Department), Mr. P. V. McMahon (Member of Council), Mr. F. W. Dyson, F.R.S. (the Astronomer Royal), Mr. W. H. Patchell (Vice-President), and Mr. P. F. Rowell (Secretary).

The PRESIDENT gave the toasts of "His Majesty the King," and of "Her Majesty the Queen, Queen Alexandra, His Royal Highness the Prince of Wales, and the other members of the Royal Family."

The Right Hon. LORD ALVERSTONE, G.C.M.G. (Lord Chief Justice), in proposing the toast of the Institution, said: I must in a very few sentences wish prosperity to this most flourishing Institution. It is one of the two Institutions that I joined as a Life Member, in hopes that it would soon come to an end and there would be a distribution of its funds. But I am delighted to say that that event is in the very far distance. I notice from the Annual Report that the Institution now has 4,350 more Members, Associate Members, Associates, and Students than when I joined, and it therefore seems to me that the event I longed for is not likely to occur in my lifetime. Gentlemen, this Institution has had already a very distinguished career, and it seems to me that its success is due largely to the fact that it adapts itself to modern requirements. You not only deal with the theoretical study of electricity in its numerous branches, but you have the practical working of electricity to take into consideration. You have now to deal with the extraordinary development in the use of electrical power; and you have not only telegraphs and telephones, but electrical tramways and electrical railways. I do not at present see much sign of electricity having much to do with aeroplanes, but I will not prophesy, because I am likely to be wrong. Why is it that this Institution has been such a success? In my judgment it is because it has commanded the support, the influence, and the services of the distinguished men of the profession during the forty years that it has been in existence. I will not refer to any living person, though there are many members of the Council now living of almost as great distinction as those I am about to refer to, and I am gratified and glad to know that this Institution still commands the support of the leaders in electrical knowledge and electrical thought. But when I mention to you six names of Past Presidents you will see what I mean when I say that this Institution had the benefit in past years of some of the greatest men in science this country has ever seen. I refer to one who was an intimate friend of my father and myself, the late Sir

William Siemens, one of the most remarkable men from the point of view of invention and science that either Germany or this country ever saw. I am delighted to know that a gentleman of that name is still amongst the distinguished Members of your Council, and one who has been a Past President. I remind you of Latimer Clark, one of the pioneers in Atlantic telegraphy; and I couple with him the name of Sir Charles Bright, himself also one of the men engaged on the first cable across the Atlantic. Then there is my distinguished friend, called away too early, John Hopkinson, one of the brightest intellects and enlightened characters that I ever knew; and that very distinguished man, Professor Ayrton, also called away too early. I have left one name because it is the greatest of them all, a leader of men in electrical and other science. The great Lord Kelvin honoured this Institution not only by being a member of it, but by three times serving in the office of President. I am glad to know, as I have already said, that the Institution commands the support, and has the advantage of the guidance, of the distinguished men of the present day in electrical science, and I have no doubt that its career in the future will be as successful as it has been in the past. I ask you, gentlemen, to join with me in drinking the health of the Institution, and I couple with that toast the name of the President, Mr. Ferranti, who is now entering on his second year of office.

The PRESIDENT (Mr. S. Z. de Ferranti), in responding to the toast, said: I must first of all tell you how great an honour I consider it is to have the privilege of being here during a second year of office to address you at your Annual Dinner. It is indeed a great honour to be President of this Institution, as it is an honour to be even a Member of your Council. This honour, however, carries with it a grave responsibility—a responsibility that one must feel very keenly indeed. We are passing through different phases of electrical development, and in so doing we see that we have different things to do and different ideas to look after from those which had to be attended to in the past. In this changed state of affairs, when electricity as you know it in the Institution, is not merely a scientific thing which can be dealt with by means of reading, listening to, and discussing scientific papers; when it is no longer confined to that particular portion of electricity owing to the changes which are taking place, I feel that the Institution is developing into, and must develop into, the guardian of the electrical interests of the country. With that idea in mind you can see what I mean when I refer to the feeling of responsibility on the part of the principal officers of the Institution. The Institution has already done something in the direction of looking after electrical interests, and it has very much more before it to do. Perhaps the most important thing that it can do, in the first case, is to persuade the electrical industry, where they do not already realise it, that there are no divergent interests; that we are all working for a common cause, and that success in that cause must be to the advantage of every one of those concerned in this Institution. That is a thing which can only be brought about in time, this feeling of

union between the different interests which are developing electrical work. If circumstances arise, perhaps shortly, perhaps later on, which make you feel that one branch of the industry or the profession is on one side and another branch is on the other, I hope you will then stop to think of what has been said to-night, and you will remember that after all, though perhaps there are apparently divergent views for the moment, you are really fighting in the same cause, namely, the development and progress of electricity. The Institution is, I think, most happy in the result of the step it took some few years ago, when it initiated the policy of having its own building. The first step in the unification of electrical interests has been brought about by the very facility which our Institution has been able to give to almost all electrical interests to meet at its headquarters; and by the very fact of these different interests meeting at our headquarters it has shown by the best lesson possible that they are all striving after the same end. You will be pleased to know that at our building on the Embankment the Institution of Post Office Electrical Engineers has met; the Municipal Electrical Association has also met there, and several other Societies, such as the Faraday Society, and the Röntgen Society. Then the following Associations have held meetings in our building: The National Electrical Manufacturers, the Electrical Contractors, the Association of Municipal Engineers of Greater London, the Junior Institution of Engineers, the Society of Engineers, and the Committee for the Protection of Electrical Interests, the Committee which has in hand the publicity of electrical work for its greater development, especially in London, and the country generally. I think it has been a most happy, a most fortunate thing that you, as the Institution of Electrical Engineers, have been able to promote development and harmony in these other branches of electrical work. There is another great work which has been going on; it is not actually new, but it is an old thing in a new light. We have always had powers to have amongst our membership those interested in the development and progress of electricity. They need not be purely scientists or purely technical men. On the other hand, this idea has not been recognised sufficiently fully or to the extent necessary to make the idea advantageous. Now we have a new spirit, or the old idea in a new form; and many of us feel —I am sure most of us—that we want to broaden our basis so as to take into our Society all those whose work is concerned with the development and progress of electrical enterprise. I am sure that, from a scientific point of view, we shall lose nothing by such a procedure, and from the point of view of benefiting the development of electricity in this country I am sure we must gain immensely. That is a work which is going on; it is a work which has had the earnest attention of your Council now for some time as to how it is best to be carried out; and I am sure that when full provision has been made, and this provision has been acted upon, the Institution will be so much the more useful, so much the stronger by the change that has been brought about. In this country electricity has been handicapped in

many ways. I will not enter into that question now, but it is one of the reasons why we have not had so far a greater development than has taken place. One of these handicaps, one of these means of retarding progress, has been the very great difficulty in the getting of wayleaves to take electricity about the country. We are handicapped more than any other country in the world in this way; and I for myself cannot see any reason why we should suffer in this way, or for whose good it can possibly be. Your Council took up this question some time ago, and they have been looking into it with the view to seeing how matters could best be improved; how first to educate the community on the subject, and how afterwards to take effect of the knowledge which they are in a position to give. I hope that in the future the continuation of this work may bear fruit. Again, another thing which undoubtedly stops development at the rate that one would like to see is the question of the price of electricity. This, of course, is not the only thing which stops electrical development, but it stands to reason that it is one of the influences, and that it is the most important one of them all. It is largely due to the unfair way in which electrical enterprises have been treated, by reason of which they have been so handicapped, that they have not been able to work to the best advantage. Still, we hope to be able to show by papers, and perhaps lectures and different educational work, that the salvation of electrical supply lies in cheapening it, and doing it on an immensely greater scale. All of us who are concerned in the success of electrical work will, I am sure, benefit if the Institution can do anything to bring about such a result as this. You will remember that some time ago it was felt there was no one to look after electrical interests in this country, and a very influential and large Committee was formed, having the title of "The Committee for the Protection of Electrical Interests." That Committee has for some time past been considering the matter and seeing how best they could help. I am pleased to say that that Committee is in process, shall I say, of absorption by the Institution, or making an arrangement for working with the Institution, so that the results it arrives at can be put into effect and forced on by the whole power which the Institution has behind it. I am sure that this will be most beneficial. There is another thing we have in our minds, and on which I hope you will also agree with me. There are various interests represented by our Institution, though, as I say, none of them are divergent, but still they are distinct interests. The different sections of our membership have different requirements. I believe that it is the business of the Council of the Institution to see what are the various interests of these different sections, and if those interests are fair and reasonable to bring the whole weight of the Institution to bear to help each particular section as it requires help. I hope that the spirit of good understanding will prevail among you; that you will all work for the one cause of progress in electrical development which is so dear to us; and if the Institution can do anything to help in this direction, I am sure that it has a bright future before it; that you will all be grateful to it, and that we shall all benefit by it.

Professor SILVANUS P. THOMPSON, F.R.S. (Past-President), in proposing the toast of "Our Guests," said :—Mr. President, My Lords and Gentlemen : In the absence of our revered Past President, Mr. Spagnoletti, and by grace of another Past-President, Mr. Alexander Siemens, I am permitted in the place of the Senior Past-President to propose the next toast. This Institution has always made a practice of inviting to its board guests who it believed would be an honour to us in coming here, and who might possibly learn something of the ways of electrical engineers. We have been unusually fortunate to-night, fortunate as we have been almost always in securing guests of great eminence. But we are here specially this year to support the policy of our President. He laid down, when he took office, a distinct line of policy, trying to open out the avenues of usefulness of this Institution in larger ways. There is not one of us who would not support our President in the idea that our Institution is to be made of more use in the world, and of greater fame ; and if we are to be of more use in the world as electrical engineers it must needs be that we associate with ourselves those who are powerful of influence in the wider world in many walks of life. If we are to have that general recognition of the usefulness of electricity ; if the programme of "electricity for all and everything by electricity" is to be carried out, it must be because we enlist the sympathies, the services, the co-operation of others than ourselves, of those in whom we recognise representatives in our guests to-night. I need not enlarge on the great success which has attended the invitations that we have sent to our guests, and as we have them here we cannot do better than drink their health and wish them all long life and many days.

The RIGHT HON. SIR GEORGE H. REID, P.C., G.C.M.G. (High Commissioner for the Commonwealth of Australia), responded on behalf of the guests.

Contractors for Advertisements:
Walter Judd, Limited, 5, Queen Victoria Street, Mansion House, E.C.

UNWIN BROTHERS, LIMITED, THE GRESHAM PRESS, WOKING AND LONDON.

No. 213. MAY, 1912. Vol. 48.

JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

ORIGINALLY

THE SOCIETY OF TELEGRAPH ENGINEERS.

FOUNDED 1871. INCORPORATED 1883.

EDITED BY P. F. ROWELL, SECRETARY.

CONTENTS

E. AND F. N. SPON, LIMITED, 57, HAYMARKET, LONDON, S.W.

SPON AND CHAMBERLAIN, 123, LIBERTY STREET, NEW YORK.

PRICE FIVE SHILLINGS

Eng. Henderson

Barksdale

JOURNAL

OF

The Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 48. 1912. NO. 213.

Proceedings of the Five Hundred and Thirtieth Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, 11th January, 1912—Mr. W. DUDDELL, F.R.S., Vice-President, in the chair.

The minutes of the Ordinary General Meeting, held on 14th December, 1911, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Hall.

The following list of transfers was announced as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members:—

Frederick M. Nicholl.	Edward A. Shrimpton.
Francis C. Polden.	Arthur A. Watkins.

From the class of Associates to that of Associate Members:—

Vero M. Allen.	Frederick H. Rudd.
John H. Bunting.	Albert C. Soutter.
Harold R. G. Forster.	John F. Tester.
Herbert W. Ridley.	Harold West.

James Cooper Wilson.

From the class of Students to that of Associate Members:—

Arthur R. Alderson.
James E. Andrews.
Russell H. Bartley.
Edgcumbe R. Brighten.
Arthur W. Brown.
William F. Brown.
William Browning.
Albert E. Clayton.
William W. Greenwood.
Roger Ernest Grime.
Walter F. Higgs.
Frank M. Lines.
Francis Eden Meade.
Edward H. Pollett.
Albert Rushton.
John Ambrose Sadd.
George H. Sargent.
Arnold Southall.
R. J. Spencer-Phillips.
Claude S. Taylor.
Frank E. Tilley.
Bernard A. Tubini.

Messrs. R. Grigg and G. C. Allingham were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Members.

Joseph Grosselin.
Robert Francis Hayward.

As Associate Members.

Herbert Bailey.
John M. M. Booth.
William Howard Buswell.
Cecil Leonard Cartwright.
Frederick Charles Clarke.
Sydney Cohen.
Charles Ernest Gray.
Rowland Austin Harris.
Raymond A. Harrison-Watson.
Frank de Betham Hart.
John Stringer Hinchliffe.
Freeman Horn.
Lieut. Charles Horace Malden, R.M.L.I.
Daniel Nordwald.
Harry Charles Osborne.
Lewis Owen.
Gian Giacomo Ponti.
Lieut. Walter C. H. Prichard, R.E.
Norman Brooke Radcliffe.
Thomas Edward P. Stretche.
Joseph Bow Tannahill.
Robert Arthur Williams.

As Students.

Edwin James Barnett.
Walter Harold Beddy.
Douglas Joseph Bolton.
Harry Booker.
Arthur Stanley Bruce.
Leonard Charles Budd.
George Hill Campbell.
Walter Henry Chatten.
Thomas John C. Clark.
Peter Nisbet Cunningham.
William Henry Date.
Charles Lizars Dobbie.
Joseph P. Duggan.
Robert James C. Durant.
Cyril Arthur I. Elkins.
Edward Frederick Evenden.
John Reid Fletcher.
James Forbes.
Johan Gustaaf A. Gerritt.
William Gilbert.
Rupert Waldemar Goetze.
Douglas Cecil Goodswin.

ELECTIONS—*contd.*

Vincente Gutierrez.
Horace Hector H. Headwards.
Charles P. Higham.
Harold Hobson.
Atholl Charles Howard.
Forbes Jackson.
Cyril William Millar.
Frederick Burrell Morfitt.
Alexander Michael Morrison.
Amulya Charan Mukhejee.
Gerald Richard Nichols.
Norman Edwin Paine.
Montague James Pattison.
Arthur Harold Perrett.
David Poe.
Arthur Edward Power.
James Nisbet Robertson.
Burgess Evelyn C. Robinson.
Frank Davis Shaw.
Eric Conrad H. Slater.
Bertram Allen Turner.
Clement Ralph Turner.
Albert Ernest Turnham.
John Trevor Weston.
Thomas Davis Williams.
Andrew Yates Young.

Donations to the *Library* were announced as having been received since the last meeting from J. W. Barber, C. Bright, F.R.S.E., F. Broadbent, Gauthier-Villars, K. Hedges, W. Matthews, Max Kohl, A.-G.; J. D. Milne, Hon. R. C. Parsons, the Physical Society of London, S. Rentell, and F. Wigglesworth & Co., Ltd.; to the *Museum* from W. Duddell, F.R.S., the National Telephone Company, and J. C. Chambers; to the *Building Fund* from J. H. Garratt and W. T. Taylor; and to the *Benevolent Fund* from W. Duddell, F.R.S., J. G. Lorrain, A. E. A. Ridgway, and C. H. Wordingham, to whom the thanks of the meeting were duly accorded.

The following paper, "Some General Principles involved in the Electrical Driving of Rolling Mills," by C. Antony Ablett, B.Sc., was read and discussed (see page 592), and the meeting adjourned at 9.55 p.m.

SOME GENERAL PRINCIPLES INVOLVED IN THE ELECTRICAL DRIVING OF ROLLING MILLS.

By C. ANTONY ABLETT, B.Sc.

(*Paper received 26th September*, 1911, *received in final form 22nd February*, 1912. *Read before* THE INSTITUTION *11th January*, 1912, *before the* YORKSHIRE LOCAL SECTION *10th January, before the* NEWCASTLE LOCAL SECTION *26th February*, 1912, *and before the* BIRMINGHAM LOCAL SECTION *27th March*, 1912.)

INTRODUCTION.

The power which is required to drive a rolling mill generally varies rapidly between wide limits, while the condition that power should be generated cheaply is that the demand made for power on the generating plant should be maintained steadily at the full capacity of that generating plant.

To ensure that the working costs of a rolling mill should be low, means must be found for reducing the fluctuations in the power required to drive the mill, care being taken in doing this that the capital cost of the plant is not unduly increased nor is the possible output reduced.

Any reduction of the possible output is equivalent to an increase in the working cost, as the capital charges per ton are increased.

The variations in power are reduced by employing a flywheel in conjunction with the electric motor which is used to drive the rolling mill, and by providing some device for reducing the speed of the motor and flywheel to enable the flywheel to give out some of its stored energy when the demand for power is great, so as to reduce the power which has to be furnished by the motor.

When the demand for power is small the motor will speed up the flywheel, thereby replacing its stored energy; this increases the power which the motor has to supply when the demand made by the mill is small, and therefore reduces the total variation in power.

In making the above general observations, it must be borne in mind that the character of the variations in the power which is required to drive the rolling mill depends on the type of mill to be driven.

Leaving large reversing rolling mills out of consideration, the largest variations in power occur in tin-plate and sheet mills. With merchant mills and bar mills the variations in power are less, while in the ordinary looping mill for rolling wire rod, where the rod may be in six pairs of rolls at once, and where a fresh rod is entered while the previous one is still in the rolls, the power required to drive the mill does not vary much.

A special case is that of a tyre mill, where the variations in power are considerable, but where the power demand remains pretty steady for nearly a minute, so that a flywheel would not prove of much benefit in reducing the fluctuations in power unless it were very heavy indeed.

The remarks about power generation apply to the case of a works generating its own power. Where power is being bought from a power company the system of charging may considerably modify the arrangement of the drive to be adopted, in order to obtain the cheapest possible working costs. This point is entered into more fully later on.

Action of Motor and Flywheel.

It is stated above that in using a flywheel in conjunction with an electric motor some device must be adopted for reducing the speed

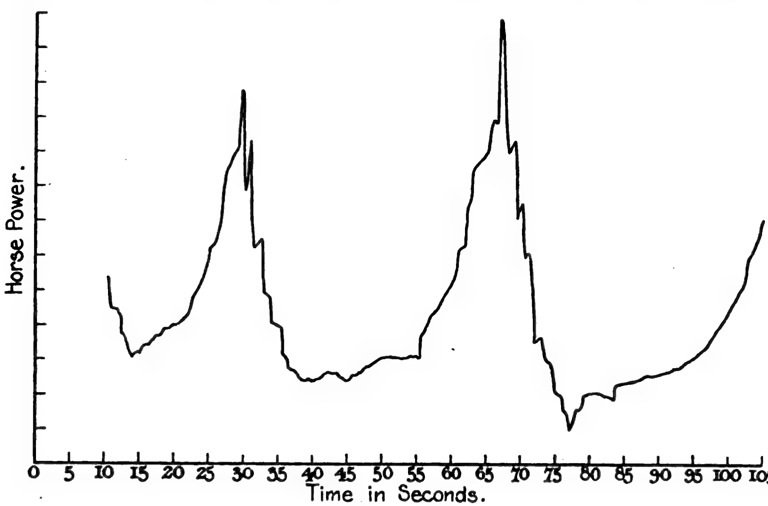


Fig. 1.—Typical Case showing Variation in Power of a Motor Driving a Sheet Mill.

when the demand for power is great. This point requires a little consideration. The ordinary direct-current shunt-wound motor, or 3-phase induction motor running at light load, will fall in speed by, say, 2 per cent. when it is required to give its full power.

The stored energy of the flywheel varies as the square of the speed at which it is running, so that if a flywheel were used in conjunction with this motor it would only give up 4 per cent. of its stored energy as the power increases from light load to the full power of the motor. Continuing this argument further, suppose that the rolling mill required during a pass a power equivalent to 4 times the normal full-load power of the motor for a few seconds. Commercial motors will not give more than twice the normal full-load power for a few seconds without being

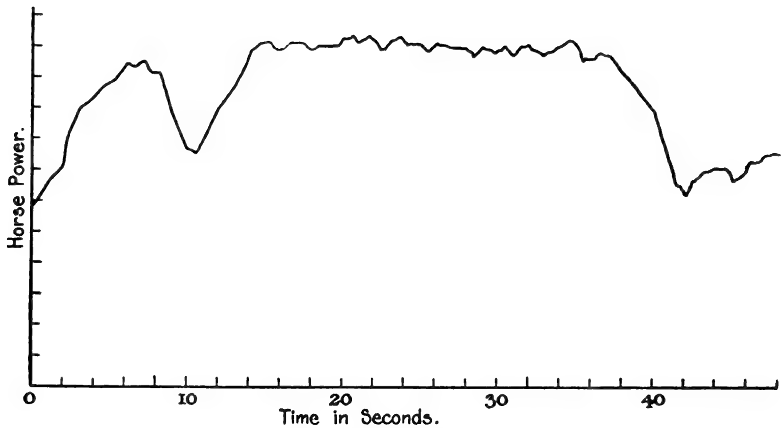


FIG. 2.—Typical Case showing Variation in Power of a Motor Driving a Looping Mill.

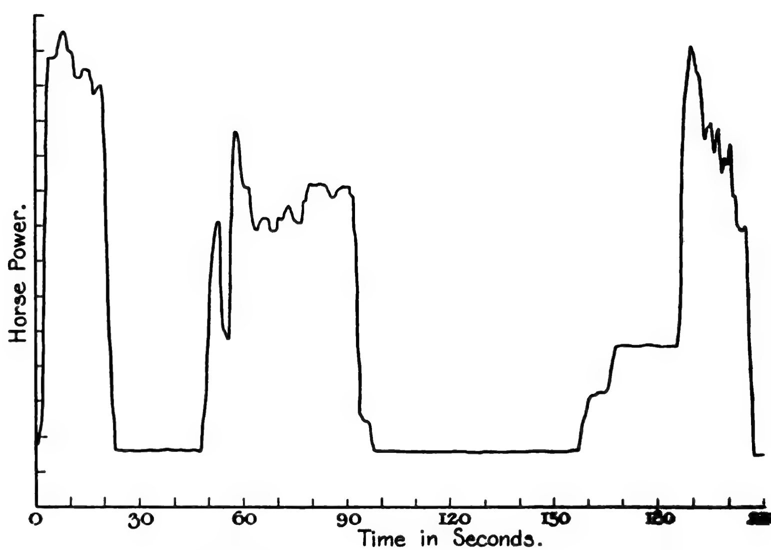


FIG. 3.—Typical Case showing Variation in Power of a Motor Driving a Tyre Mill.

liable to injury, and to prevent this the circuit breaker is usually set to open at the current corresponding to this power. The flywheel, therefore, has to furnish the power which is in excess of that which the motor can give.

In the case considered, the motor would fall perhaps 5 or 6 per cent. in speed when the power increased from light load to double full-load power, so that the flywheel would only give up 10 or 12 per cent. of its stored energy.

The flywheel would, therefore, have to be abnormally heavy, or else if a flywheel of a weight within the bounds of commercial possibility were adopted, the combination would be unable to cope with this demand for power, and the motor power would increase until the circuit breaker opened.

It is therefore necessary artificially to increase the fall in speed of the motor as the power which it has to give increases. If the speed falls by, say, 10 per cent. as the power increases from zero to full load, and, say, by 22 per cent. as the power increases to the double full-load power, the flywheel would have given up 39 per cent. of its stored energy by the time that the motor was giving double its normal full-load power, instead of from 10 to 12 per cent. A flywheel, therefore, of moderate weight would materially assist the motor in overcoming heavy demands for power which last for a short time only.

In practice the maximum power given by the motor would seldom be as much as double the normal power, nor would the motor power sink to zero, as even when nothing was being rolled the motor would still have to provide the power for overcoming the friction of the mill, which is considerable.

There are two possible devices for artificially increasing the fall in speed of the motor as the power demanded increases. These are commonly spoken of as :—

1. The permanent-slip regulator.
2. The automatic-slip regulator.

This last term is misleading because both devices perform their functions automatically, the difference between them being that with the first the amount of fall in speed or the slip steadily increases as the power increases, while with the latter the fall in speed increases suddenly after a definite power is attained.

It would therefore be better to call these devices :—

1. The continuous-slip regulator.
2. The intermittent-slip regulator.

For reasons explained later on, the continuous-slip regulator is the device which is more commonly used in practice.

It should be explained that in the case of the direct-current motor the continuous-slip regulator consists of an ordinary compound winding

provided for the field-poles, while the intermittent-slip regulator consists of a system of relays which successively short circuit resistances in series with the shunt field winding, thus increasing the field and causing the speed to fall when the power has reached a certain predetermined point.

In the case of the 3-phase motor, the continuous-slip regulator consists of a resistance, liquid or metallic, permanently inserted in the rotor circuit, while the intermittent-slip regulator may consist either of a liquid resistance, the moving plates of which are controlled by a motor relay, so that the plates are raised and the rotor resistance increases when the current has reached a predetermined point, or a metallic resistance which has its various sections short-circuited by a series of relays, so arranged that these relays cut the resistance into the rotor circuit when the current has reached the predetermined limit.

As the continuous and intermittent-slip regulators are essentially different in their action, it is desirable to consider the action of each in detail.

Continuous-slip Regulator.

For the sake of simplicity, it is assumed that the fall in speed of the motor or slip below no-load speed is proportional to the power which the motor is giving. This is not strictly true, but the modification of the results which this slightly erroneous assumption introduces will be considered later on.

Within the limits of fall in speed or slip of the motor it can be assumed that the stored energy given up by the flywheel is proportional to the slip, without involving any large error, therefore the power given by the flywheel is proportional to the rate of change of the slip—that is, to the rate of change of the motor power. It will thus be seen that if a sudden increase of load is imposed on the motor and flywheel by entering a bar between the rolls, and a curve is constructed showing the increase of motor power with the time, this curve will be a logarithm curve; while if the power required by the mill suddenly decreases owing to the bar leaving the rolls, the motor power decreases according to a logarithm curve. The curves showing the rise and fall in speed of the motor and flywheel are also corresponding logarithm curves.

After the bar leaves the rolls the power which the motor gives while decreasing to the value corresponding to the friction goes to increase the speed of the flywheel, and so replaces its stored energy. These curves are quite analogous to those for the heating and cooling of electrical machinery; the power of the motor, however, rises to practically its full value in a few seconds, while the temperature of an electrical machine takes a number of hours to reach approximately its full value. We may illustrate this reasoning by mathematical symbols as follows:—

Let—

P = power required to drive rolling mill when bar is between rolls.
K_{s1} = full-load power of motor.
s_1 = slip of motor at full load.
v_0 = speed of motor at no load.
v = speed at which motor is running at any particular time.
s = corresponding slip.
I = moment of inertia of flywheel.

$$\text{Stored energy of flywheel} = \frac{I v^2}{2};$$

supposing speed of flywheel is reduced from v_0 to v,

$$\text{Stored energy given up} = \frac{I (v_0^2 - v^2)}{2}$$

or—

$$\frac{I}{2} (v_0 + v)(v_0 - v);$$

$v_0 - v$ is the slip s, and $v_0 + v$ may be put equal to $2v$ without making much error.

Stored energy given up by the flywheel is—

$$I v s;$$

that is, the stored energy which has been given up is proportional to the slip.

The sum of the power given by the motor and the flywheel must be equal to the power required to drive the rolling mill. We can express this by the linear differential equation—

$$I v \frac{\delta s}{\delta t} + K_s = P,$$

the solution of which is—

$$\text{Motor power } K_s = P\left(1 - \varepsilon^{-\frac{Kt}{Iv}}\right)$$

showing that the motor power increases according to a logarithm curve.

Similarly, when the bar is out of the rolls the motor power is equal to the power taken to speed up the flywheel, thereby restoring its stored energy, or—

$$I v \frac{\delta s}{\delta t} + K_s = 0;$$

the solution of this is—

$$\text{Motor power } K_s = P \varepsilon^{-\frac{Kt}{Iv}},$$

showing that when bar is out of the rolls the motor power decreases also according to a logarithm curve.

The friction of the mill has been left out of these calculations for the sake of simplicity, but it can be very easily taken account of in drawing the curves by shifting the zero line.

The expression $\frac{I\,r}{K}$ expressing the relation of motor power to flywheel capacity is the "time constant" in this case and is exactly analogous to the "time constant" in the case of the heating or cooling of electrical machinery.

The value of the time constant for a motor and flywheel, however, does not usually exceed about 33 seconds. The value of the time constant to be selected naturally depends on the type of mill. In a

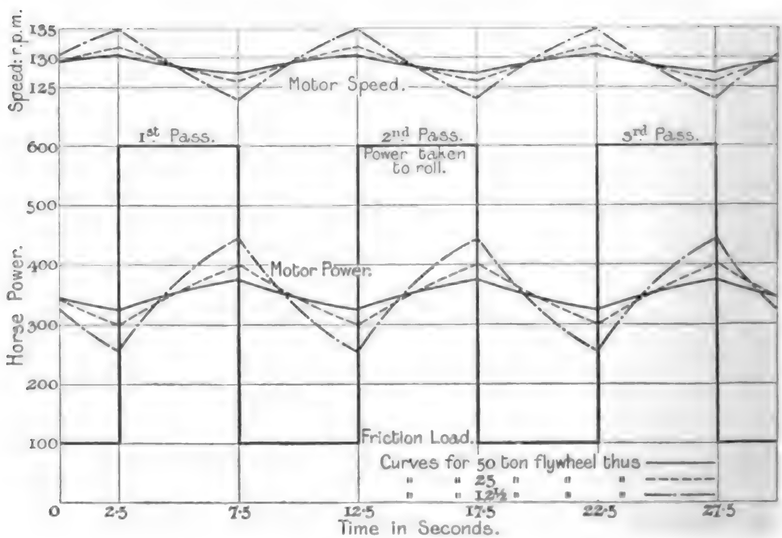


FIG. 4.—Curves showing Variation of Motor Power and Speed for 50-, 25-, and 12½- ton Flywheels. Pass, 5 seconds; Interval, 5 seconds.

sheet mill where the duration of the passes is very short the time constant need not be so big as in the case of a bar mill, where the finishing passes may take a considerable time. The greatest time constants are found in the case of motor and flywheel for the motor-generator set of an Ilgner electrically driven reversing rolling mill.

Figs. 4, 5, 6, and 7 are drawn to show the rise and fall of the power of a motor provided with a continuous-slip regulator and used in conjunction with a flywheel, and to show how this variation of power changes as the respective times of the pass and interval change.

In each case it is supposed that during each pass 500 H.P. is required to roll the bar and 100 H.P. to overcome the friction of the mill, so that a total of 600 H.P. is required during the pass, and the power falls to the friction load, namely 100 H.P., during the interval.

Fig. 4 shows the case where the pass lasts 5 seconds and is succeeded by an interval lasting 5 seconds.

Fig. 5 shows the case where the pass lasts 5 seconds and is succeeded by an interval lasting 2½ seconds.

Fig. 6 shows the case where the pass lasts 2½ seconds and is succeeded by an interval lasting 5 seconds.

Fig. 7 shows the case where the pass lasts 15 seconds and is succeeded by an interval lasting 15 seconds.

In each figure three curves are shown, the first supposing a flywheel weight of 50 tons, the second a weight of 25 tons, and the third 12½ tons, it being assumed that the continuous-slip regulator remains unaltered in each case.

Since the energy which is taken from the flywheel during the pass is replaced again in the interval between passes, the average power for any particular figure remains the same whatever weight of flywheel is used, but the percentage variation of power and speed is less with the heavy wheel than with the light wheel. When the relation of the time of the pass to the time of the interval is changed the average power naturally changes, the average being less where the interval is long, and greater where the interval is short.

The following table shows how the percentage variation in power changes with different weights of flywheel and with various durations of pass and interval :—

	Average Power.	Percentage Variation of Power.		
		50-ton Wheel.	25-ton Wheel.	12½-ton Wheel.
	Horse-power.	Per Cent.	Per Cent.	Per Cent.
Fig. 4 (pass 5 seconds, interval 5 seconds)	350	14·2	28·2	54·5
Fig. 5 (pass 5 seconds, interval 2½ seconds)	433	7·7	15·3	30·0
Fig. 6 (pass 2½ seconds, interval 5 seconds)	267	12·6	25·0	48·5
Fig. 7 (pass 15 seconds, interval 15 seconds)	350	41·8	76·0	120·0

In this table the percentage variation is expressed with relation to the average power.

It is thus possible to obtain variations greater than 100 per cent.

The table shows that the percentage variation of the power increases as the weight and consequently the stored energy of the flywheel decreases, but that this increase is not proportional to the

decrease of stored energy, but increases at a slower rate than the stored energy decreases.

Although for each particular figure the average power remains the same whether a light or a heavy flywheel is employed, a somewhat larger motor would be required with the light flywheel than with the heavy wheel, because the motor size is settled by the root mean square current and not by the average current, and where the variation of power is great the root mean square value is naturally greater than where the variation is small.

In the curves shown in Fig. 7 the average power is 350 H.P.

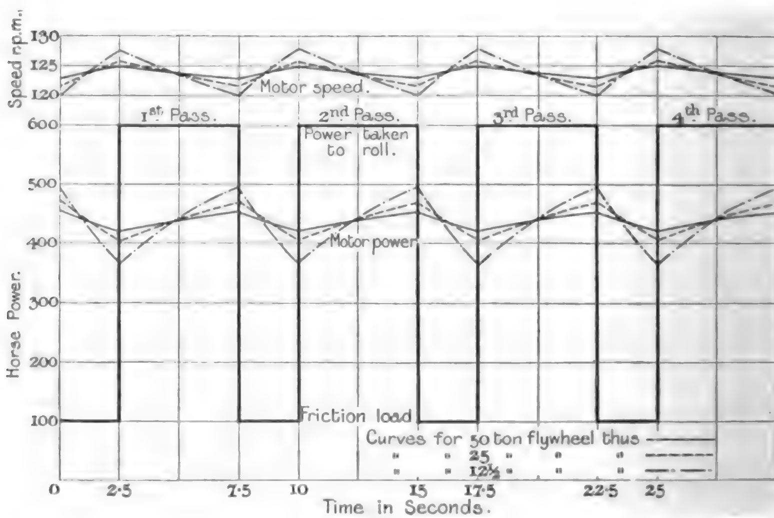


FIG. 5.—Curves showing Variation of Motor Power and Speed for 50-, 25-, and 12½-ton Flywheels. Pass, 5 seconds; Interval, 2½ seconds.

Where a 12½-ton wheel is used, the root mean square power is 379 H.P., so that a motor of this power would have to be installed.

Where a 25-ton wheel is used the root mean square power is 360 H.P.

Where a 50-ton wheel is used the root mean square power is 354 H.P.

If no flywheel at all were used the root mean square power would be 430 H.P.

Comparing the case where no flywheel at all is used with the case where a 25-ton flywheel is used, it will be seen that in the former the motor would have to be 20 per cent. larger.

It should be noticed that the speed of the motor and flywheel rises and falls in accordance with the logarithm curves which vary inversely as the power.

If Figs. 5 and 6 are compared, it will be seen that in each case the actual amount by which the power varies is the same, but in Fig. 6 the percentage variation of power is much greater because the mean power is less.

It will also be noticed that the power curves in Fig. 6 are exactly similar to those in Fig. 5, but they are turned upside down. This is merely a coincidence, because in one case the duration of the pass is twice the interval, while in the other case the duration of the interval is twice that of the pass, so that one case may be said to be the inverse of the other.

If the slip of the motor were plotted instead of the speed of the motor, the curves for increase and decrease of slip would be exactly similar to the power curves.

Alarm is raised from time to time in cases where work is being carried on very rapidly so that there is only a very short interval between passes, to the effect that the flywheel may not have time to recover itself between the intervals and passes. Such alarm is entirely without foundation, and this is illustrated by Fig. 5.

If the intervals are short, then naturally the average power increases, while the percentage variation of power is reduced. As the average power is increased the motor is supplying greater power to the flywheel during the interval, and although this interval may be short it is able to restore the stored energy of the flywheel.

Fig. 7 shows that where the passes are long the flywheels are less effective in reducing variations of power than where the passes are short, because the time constant of the motor and flywheel become comparable with the length of the pass, so that the motor is giving nearly the full power required by the rolling mill towards the end of the pass, and the flywheel is not giving out much power. In such cases heavy flywheels are required if the percentage variation in power is to be kept small.

The following general conclusions may be drawn from these curves, namely :—

1. If the time during which the pass lasts is short, and the interval is also short, light flywheels will reduce the percentage variation in power to a small value, while if the time of passes is long, and the intervals are also long, heavy flywheels are required.
2. Where the time of the interval is short compared with the time of the pass a light flywheel will enable the percentage variation of power to be kept moderate, but if the time of the interval is long compared with the time of the pass, the heavier flywheels must be used.

In practice the question is not so simple because, as is pointed out later on, the various passes in rolling down a billet to a definite section require widely differing powers, while the time of the passes and of the intervals also differ widely.

The effect of the errors introduced by the assumption made in the above theoretical considerations may now be considered. To simplify calculation, it was assumed that the stored energy given up by the flywheel is—

$$I\,v\,s,$$

and not—

$$\tfrac{1}{2}\,I\,(v_0 + v)\,s\,;$$

that is to say, the stored energy given up by the flywheel has been assumed to be rather too large, so that the variation of power will actually be somewhat larger than the calculated value. An error introduced in this way may be about 7 per cent. at the most.

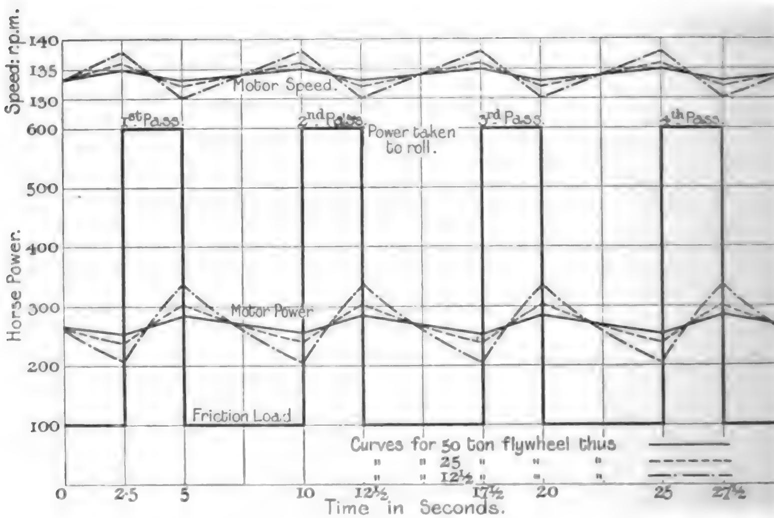


Fig. 6.—Curves showing Variation of Motor Power and Speed for 50-, 25-, and 12½-ton Flywheels. Pass, 2½ seconds; Interval, 5 seconds.

It has also been assumed that the decrease in speed of the motor is proportional to the power which the motor is giving—this also is not quite correct. In the case of a direct-current motor having a continuous-slip regulator, that is to say, a compound wound motor, the speed-power curve begins to approach that of a series motor, and as the load increases from light load the speed falls more rapidly at first than it does later on. The effect of this is to flatten the logarithm power curves for the rise and fall of power, making these curves approach more towards straight lines, and, in the case of passes of short duration, actually to reduce the variations of power. This effect becomes more marked as the compounding of the motor is increased.

With a 3-phase motor having a continuous-slip regulator—that is, a resistance connected permanently in the rotor circuit—the speed falls

less rapidly at first, when the power increases from light load, than it does later on. The effect of this is to increase the curvature of the logarithm power curves and to increase the variations of power in the case of passes of short duration.

The consequence of this is that in certain cases a heavier flywheel must be used in conjunction with a 3-phase motor than with a direct-current motor, in order to obtain the same results.

Figs. 4, 5, 6, and 7 will serve to illustrate the conditions of rise and fall of power entailed by the use of a continuous-slip regulator, but they do not in any way represent the conditions obtaining in a rolling mill.

In any mill the bar is elongated in each pass so that each suc-

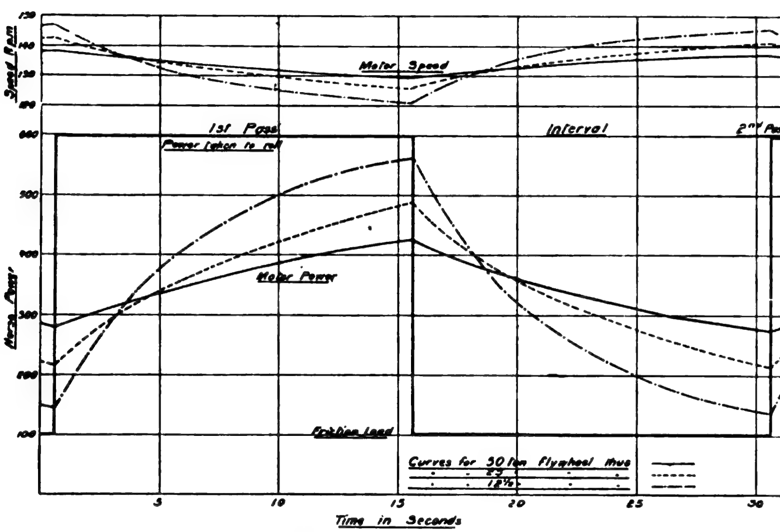


FIG. 7.—Curves showing Variation of Motor Power and Speed for 50-, 25-, and 12½-ton Flywheels. Pass, 85 seconds; Interval, 15 seconds.

cessive pass taken in the same pair of rolls takes a longer time than the previous pass.

Frequently less draught is taken in each succeeding pass than in the previous pass, so that the tendency is for the power diagram to consist in the earlier passes of large powers lasting for a short time, and for the power gradually to diminish and the time to become longer as the later passes are reached. There are many exceptions to this, too numerous to be discussed here, but mention may be made of such cases as those where the bar cools rapidly, owing to the shape of its section being such as to present a large area in proportion to its weight, so that considerable powers are required for the later passes, or where heavy draughts must be taken in certain passes, so as properly to form the section, as, for instance, in the rolling of

wagon spokes, or in the case of a sheet or plate mill where the plate is turned at right angles after a few passes in order to broaden it, thus requiring a greater turning moment and thus a greater power, owing to the increased width of plate presented to the rolls.

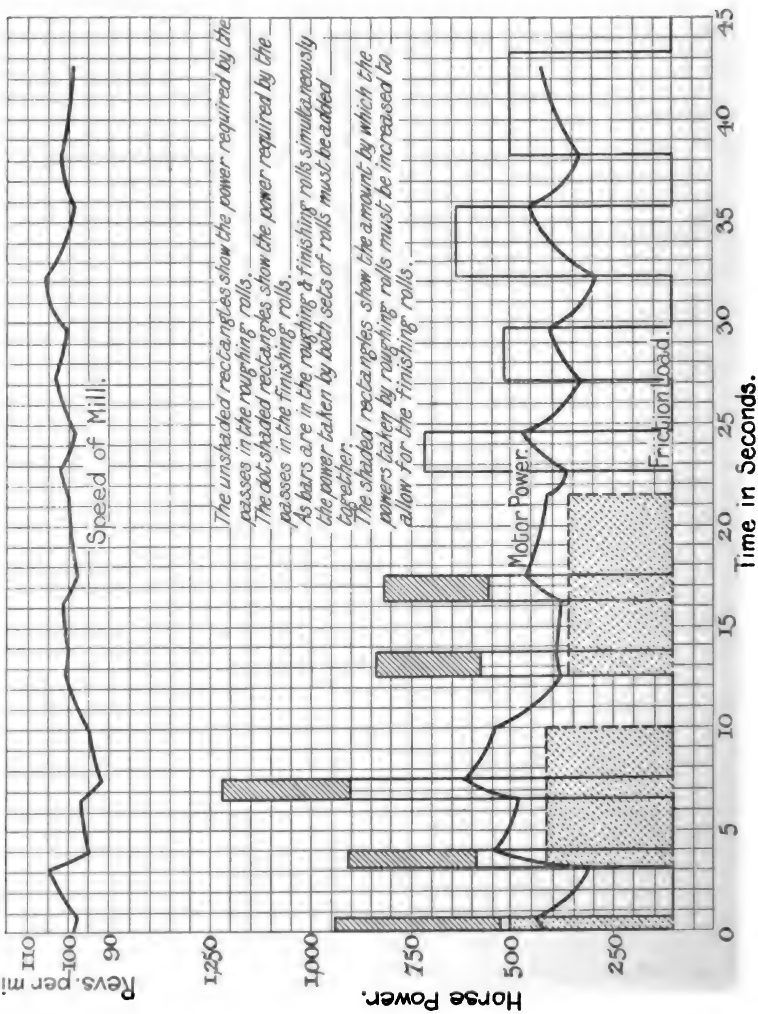


FIG. 8.—Typical Example of the Variation of the Power and Speed of a Rolling Mill Motor under Practical Conditions.

Fig. 8 is an illustration of a practical case, being a series of curves obtained for a bar mill, and this serves to show the sort of variation of power and speed to be found in practice.

It may be mentioned that the bar mill for which these curves were

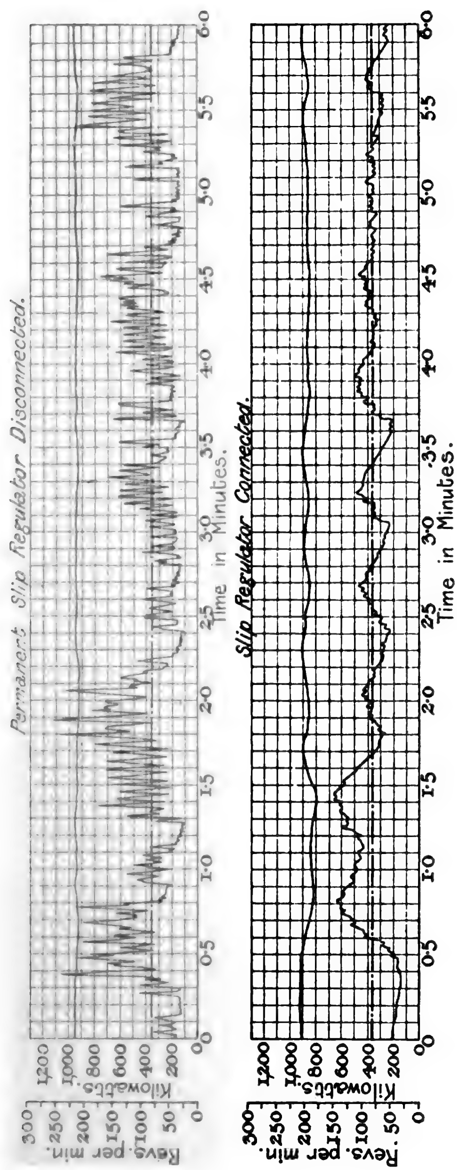


Fig. 9.—Curve showing the Benefit of a Permanent Slip Regulator for a Sheet Mill.

drawn had two stands of rolls, a roughing stand and a finishing stand, and as bars may be in both stands at the same time, account has to be taken of the power required when two passes come simultaneously.

The plain rectangles show the powers required by the passes in the roughing mill, the dot-shaded rectangles show the powers required by the passes in the finishing mill, and the shaded rectangles show the amount by which the total power is increased by adding the powers taken by the roughing mill passes to the powers taken by the finishing mill passes.

The curved lines show the motor power which reaches 620 H.P. as a maximum, although in one case, where two bars are in the rolls together, the mill requires 1,220 H.P., while the minimum value is

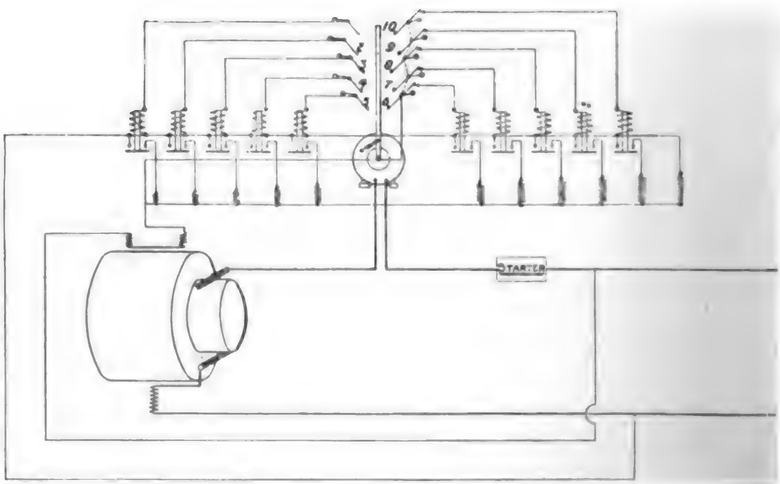


FIG. 10.—Diagram of Type of Intermittent Slip Regulator suitable for Direct-current Motors.

295 H.P. As the mean horse-power is 424, the percentage variation is 76 per cent. If no flywheel were used the percentage variation would be 267 per cent. This practical example illustrates the benefit of the flywheel in a striking manner, which is also shown by Fig. 9, in which the curves were obtained from tests.

Speed varations of 22 per cent. between no load and double full load have been mentioned above, but a little inspection of the curves on Figs. 4, 5, 6, 7, and 8 will show that no such speed variations may be expected in practice where the work at the mill is being carried out fairly steadily, because with steady working the power never comes down to no load, neither does it reach double full load except in very exceptional conditions, so that if the speed variation were 22 per cent. between no load and double full load a much less speed variation would take place when working under practical conditions. In the

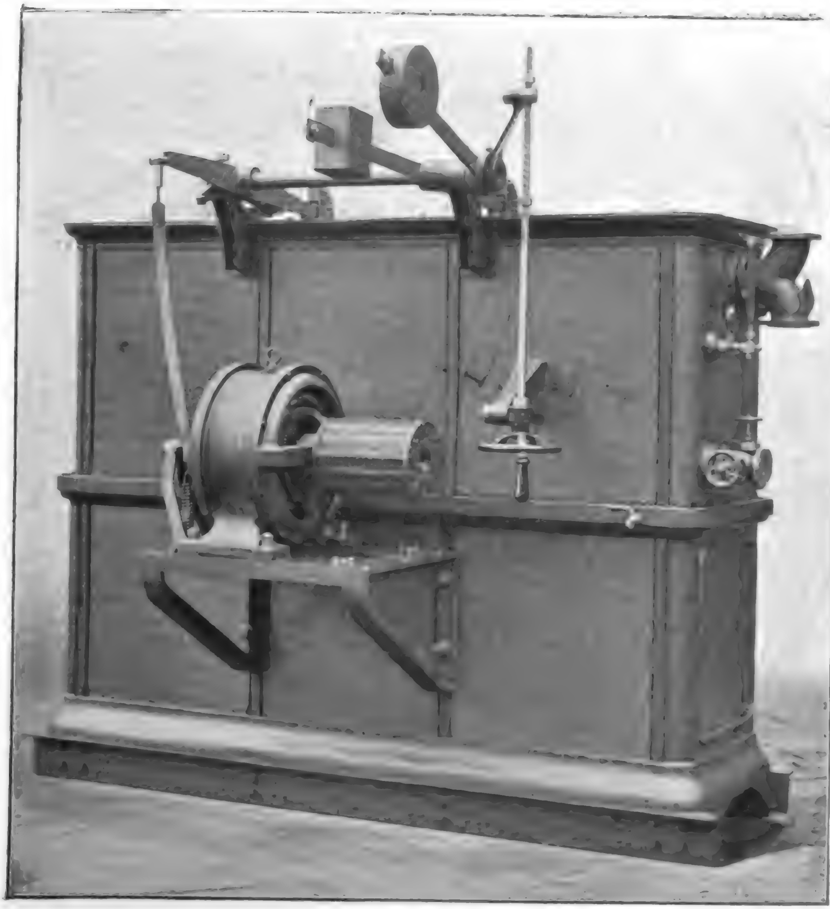


Fig. 11.

case of Fig. 8 the speed variation of the motor is 20 per cent. between no load and full load, but in the curve the speed variation does not exceed 11·2 per cent.

Intermittent-slip Regulator.

Fig. 10 shows a type of intermittent-slip regulator suitable for direct-current motors. This consists of a small motor relay which sets in operation a number of relays which successively connect resistances in parallel with the resistance placed in series with the shunt field of the motor. The field of the motor relay is excited by the main current passing through the mill motor armature. If the mill motor is small the main current passes through this field, but if the main current is too big the field is placed across a shunt placed in the mill motor circuit.

The armature of this motor relay is excited by a pressure winding which is placed across the mains supplying the main mill motor. The armature is restrained from moving by means of a spring, so arranged that when the current in the main circuit exceeds a certain value, the turning moment of the armature of the motor relay overbalances the spring, so that the armature makes a slight movement. This movement of the armature successively makes contact with a number of fingers, which energise the relays, which successively connect resistances in parallel with the resistance in the main motor shunt field.

Fig. 11 shows a form of intermittent-slip regulator adapted for use with 3-phase motors. This consists of three liquid resistances with moveable plates, one placed in each phase of the rotor circuit. A motor relay is provided in this case, the windings of the motor stator being either in series with the mains supplying the main mill motor or else supplied through a current transformer.

The rotor of this motor relay is prevented from moving, either by a spring or by a weight slung from a band passing over a pulley on the motor shaft. When the current in the main motor exceeds a certain predetermined value the turning moment given by the motor relay overbalances either the spring or the weights, allowing the armature to turn a certain amount, thereby raising the plates in the liquid resistance by means of a belt passing over another pulley on the motor shaft. The raising of these plates increases the resistance in the rotor circuit of the mill motor, thereby causing it to fall in speed.

Such intermittent-slip regulators do not find much application, because they are not rapid enough in their action to deal with the extremely rapid fluctuations in power occurring in most rolling mills.

The action of the intermittent-slip regulator is very different from that of the continuous-slip regulator. This intermittent regulator comes into action when the power given by the motor attains a certain value, and when this point is reached a very slight increase in power indeed will cause the intermittent-slip regulator to act to its fullest extent.

Theoretically speaking, therefore, the power can be maintained at its average value with a deviation of perhaps less than 1 per cent., so that the power curve is practically a straight line, and does not rise and fall in accordance with logarithm curves, as is the case with the continuous-slip regulator.

Further, it has been shown that with such variations in speed of the motor and flywheel as are permissible in practice, the stored energy given out by the flywheel is proportional to the fall in speed. Assuming, therefore, that constant power is required throughout the pass when a bar is between the rolls, and as the power given by the motor is

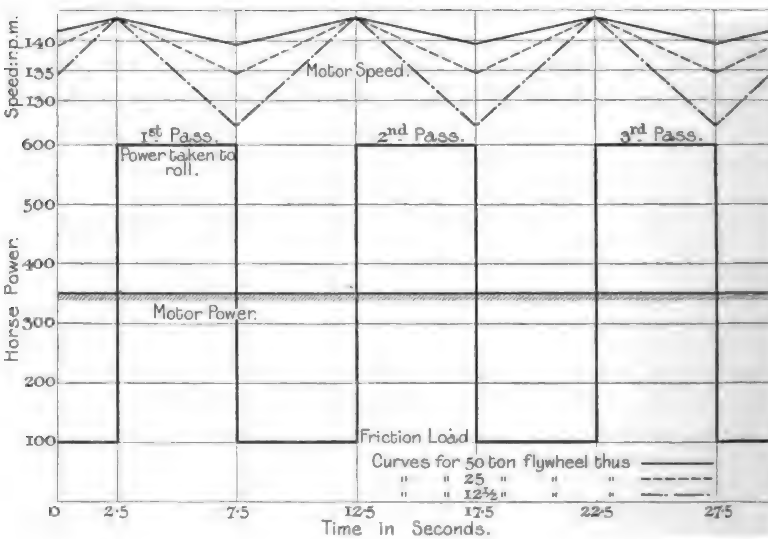


FIG. 12.—Intermittent Slip Regulator—Theoretical Action. Variation of Motor Power and Speed for 50-, 25-, and 12½-ton Flywheels. Pass, 5 seconds; Interval, 5 seconds.

practically constant, the power given by the flywheel will also be practically constant. That is to say, in each small interval of time the same amount of stored energy is to be given out by the flywheel. The speed will therefore fall during the pass in accordance with the straight-line law, and will rise again in the interval between passes, also in accordance with the straight-line law, and there will be no logarithm curves for the rise and fall in speed as is the case with the continuous-slip regulator.

Fig. 12 is drawn to show the theoretical behaviour of the motor and flywheel when provided with the automatic-slip regulator, supposing, as in the case of Fig. 4, that a power of 500 H.P. is demanded for 5 seconds, followed by a 5-second interval, and then succeeded by an-

other pass demanding 500 H.P. for 5 seconds. Three curves of speed are also shown for flywheel weights of 50 tons, 25 tons, and 12½ tons, from which it will be seen that the variation in speed is proportional to the weight of the flywheel.

The above considerations of the behaviour of the intermittent-slip regulator are based on purely theoretical grounds, and on these theoretical grounds it appears to be a very ideal mechanism as compared with the continuous-slip regulator. Engineers who have taken account of the theoretical behaviour without paying sufficient attention to the practical side, are tempted to think that the intermittent-slip regulator is the proper mechanism to use in every case of a motor in conjunction with a flywheel driving a rolling mill.

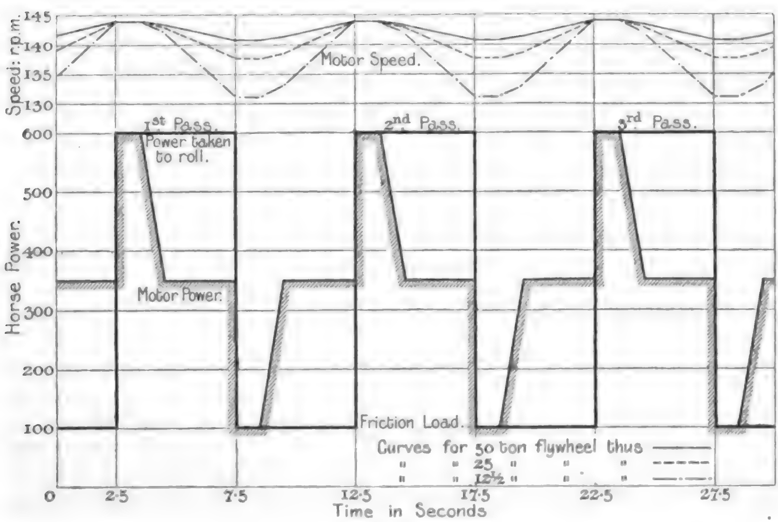


FIG. 13.—Intermittent Slip Regulator—Action in Practice. Variation of Motor Power and Speed for 50-, 25-, and 12½-ton Flywheels. Pass, 5 seconds; Interval, 5 seconds.

In practice one may say that the great difficulty with the intermittent-slip regulator is that it is comparatively slow in coming into operation on account of the inertia of the various moving parts. Such slip regulators often take from 1 to 2 seconds to come into operation, and as the power demanded from a rolling mill motor increases practically instantaneously when the rolls bite the bar, the power will rise to its maximum value before the intermittent-slip regulator can come into operation. Thus, instead of reducing the power to the mean value, as would appear to be the action of the automatic-slip regulator from theoretical considerations, it actually is the means of producing very bad peaks indeed.

Fig. 13 illustrates the practical operation of the intermittent-slip

regulator under the same conditions as shown in Fig. 12, which is drawn from theoretical considerations, and Fig. 13 serves to show how the intermittent-slip regulator can allow the power given by the motor to rise to the maximum value that is demanded by the rolls, thereby producing very bad peaks.

In many cases, particularly that of the earlier passes of a roughing mill, which is roughing down billets in order to feed an ordinary merchant mill, the passes are of much shorter duration than the 5 seconds shown in Fig. 12, and may easily be of less than 1 second duration. In such a case the intermittent-slip regulator would be absolutely useless, and unless a very large motor were provided the circuit breaker would be continually coming out.

The case of a looping mill rolling wire rod, which is shown in Fig. 2, would be a good one for the installation of the intermittent-slip regulator, because the power demanded from the motor does not rise suddenly but gradually as the rod is looped into the various pairs of rolls, and the power demanded also increases gradually, so that it gives time for the intermittent-slip regulator to come into operation.

The intermittent-slip regulator also finds application for regulating the speed of the flywheel motor-generator set for supplying an electrically driven reversing rolling mill on the Ilgner system.

Where a 3-phase rolling mill motor is used, and where the continuous-slip regulator consists of a resistance permanently in the rotor circuit, while the intermittent-slip regulator consists of a resistance which is inserted into the rotor circuit after the power reaches a definite value, the use of these resistances entails a certain waste of power proportional to the amount by which the speed falls, and it would appear at first sight that the waste of power should be less with the intermittent-slip regulator than with the continuous-slip regulator, because with the intermittent-slip regulator the resistance is not always in circuit. Careful tests have shown that this is not the case, and that there is practically no difference between the loss of power taking place in either form of slip regulator.

A little consideration will show that this must be so, because in the case of the intermittent-slip regulator the resistances are brought into circuit where the powers are large, and where a considerable fall in speed is desired, and also that when the resistances are brought into circuit there is a greater fall in speed with the intermittent-slip regulator than with the continuous-slip regulator, so that when the intermittent-slip regulator is in operation it causes a larger loss of power than the continuous-slip regulator, but the intermittent-slip regulator only cuts the resistances out of circuit when the power, and consequently possible loss of power, is small.

Arrangement of Motor and Flywheel to suit Power Supply.

The choice of the power of a rolling mill motor and of the weight of the flywheel used in conjunction with it, so as to obtain that

relation between motor power and weight of flywheel that will reduce the cost of power to a minimum, depends on whether power is being generated in a power house in the works, or whether power is being purchased from outside; and in the latter case there are various systems of charging for power which materially affect the most favourable proportions between motor and flywheel to be adopted. Some typical cases showing how the system of payment affects these proportions will be considered.

Attention must also be called to the case where there are a number of rolling mills in one works, all of which are doing somewhat similar work, and which will usually all be working together. Here the probability is greatly in favour of the variations in the power taken by the various rolling mill motors balancing one another, so that the total power required remains at a fairly constant value, even although

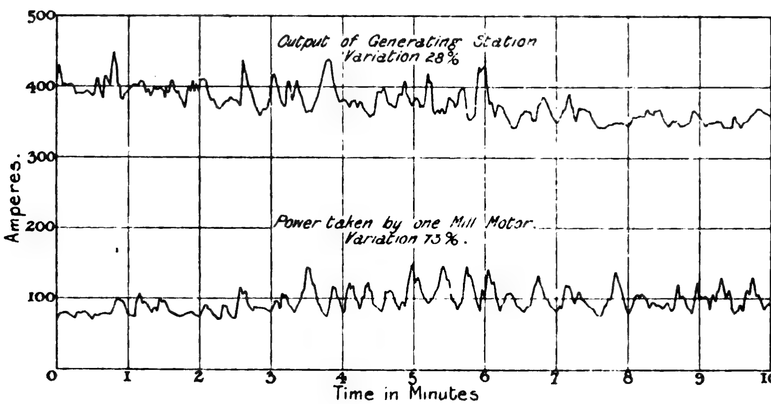


FIG. 14.—Curve showing the Effect of Natural Power Equalisation.

flywheels of quite moderate weight are used with the mill motors. Fig. 14 shows some test results which illustrate this natural balancing.

This fact of natural balancing is fully borne out by practical experience, and such a case is an ideal one for cheap electrical driving.

1. *Power generated within Works.*—In this case the power to be supplied by the power station should be kept as constant as possible. If there are only one or two rolling mill motors and a considerable amount of small machinery of which the power demand will keep fairly constant, the rolling mill motors will tend to cause considerable fluctuations of power, and to ensure that power is being generated cheaply in the power station these fluctuations must be reduced as far as possible by using heavy flywheels with the mill motors, and by arranging the slip regulators so as to allow as much fall in speed as is consistent with obtaining the output from the mills, so that as much of the stored energy of the flywheels as possible may be available for reducing fluctuations in the power.

There is a definite economic limit to the weight which may be adopted for the flywheels because increase in the weight increases both the frictional losses and the capital charges on the plant, and a point will be reached where the increase in running costs due to these frictional losses and increased capital charges will balance the saving effected by running the generating plant at constant load.

If, on the other hand, there are a large number of rolling mills, all of which are likely to be working simultaneously, it would be advantageous under certain conditions to proceed to the other extreme and to reduce the flywheel weight, relying on the natural balancing effect to keep the load constant.

Theoretically it would be possible to dispense with flywheels altogether, but this would require that the size of the driving motors should be considerably increased, and it would be found cheaper to install a moderate size motor with a moderate weight of flywheel rather than a large motor and no flywheel at all.

This reduction in the weight of the flywheels would reduce the capital charges on the plant, and by reducing the frictional losses would reduce the total power required.

In some special cases where there is a large number of mills working simultaneously, natural balancing is very difficult to obtain, as in the case of hot mills for rolling tin-plates, where the motors are only giving their maximum power for a very small fraction of the total time, and in such cases it is necessary to use heavy flywheels.

2. *Power purchased from a Supply Authority on the Maximum Demand System where Instantaneous Peaks are Registered.*—This case is similar to the above, as means must be adopted for keeping the power as near to the average value as practicable.

The following example will show the saving to be effected by keeping the power to the average value.

At a certain works where a small mill is being driven, the maximum instantaneous demand is about 260 k.w., while the average number of units taken per month is about 25,600. Payment is made reckoning the maximum demand over 75 hours per month at 1d. per unit and the remainder of the power at $\frac{4}{10}$ of 1d. per unit. The total cost of power therefore works out at £91 3s. 4d. per month.

If, however, the power during the working hours was reduced to the average—that is to say, to 53 k.w.—payment would be made for 53×75 units at 1d. per unit and for 21,600 units at $\frac{4}{10}$ of 1d. per unit, so that the cost of power per month would be £52 12s.

If, therefore, it were possible to keep the power at the average value, a saving of £38 11s. 4d. per month would be made, or £462 16s. per annum.

While this case is rather an extreme case, it shows that if a suitably heavy flywheel and a slip regulator were installed to reduce the power to the average, a very large saving would be made after paying the capital charges on this flywheel, etc.

3. *Power purchased from a Supply Authority at a Flat Rate for the*

Number of Units Consumed.—In this case all friction losses should be kept as low as possible in order to reduce the total number of units consumed, while there is no object in attempting to prevent variations in the power.

If motors large enough to deal with the largest power required by the rolling mill should be installed without any flywheel at all the friction losses would be reduced to a minimum, giving the cheapest possible power costs, while the maximum possible output could be obtained from the mill on account of the steady speed at which it would run. Such large motors, however, would prove more expensive in capital cost than a more moderate size motor used in conjunction with a flywheel of moderate weight, and it could not be generally stated that the saving in power costs due to the reduction of friction by doing without a flywheel altogether would justify the additional capital outlay, although if a large tonnage from the mill were considered essential the extra capital outlay might then easily be justified. It may be said, however, that in such a case the general tendency would be to reduce the flywheel weight and to increase the motor power.

4. *Power purchased from a Supply Authority on the Maximum Demand System where Peaks of several Minutes duration only are taken account of.*—This system of charging is much in favour with the various supply authorities, and the remarks made with regard to case 3 apply to this case also.

The variations in power required by most rolling mill motors are very rapid and the peaks last for a matter of a few seconds only, so that they will not be registered by the maximum demand indicator.

Care should be taken that the hourly output of the mill is kept as steady as possible, for if the mill were worked rapidly for an hour or two and then there was a long wait for billets to heat in the furnace, or for some other cause, this period of rapid rolling would be found to affect the cost of power very adversely. This, however, is a matter for the mill manager and does not affect the arrangement of the driving plant.

THE ILGNER SYSTEM FOR DRIVING LARGE 3-HIGH MILLS.

In the preceding sections of this paper, reference has been made to the necessity for a mill motor, when used in conjunction with a flywheel, to fall in speed when the power demand is large, so as to enable the flywheel to give up some of its stored energy, and attention has been drawn to the fact that this causes a diminution in the tonnage which the mill can roll.

The speed of a rolling mill is settled by the first passes in the roughing rolls, because in these passes the billet is very short, and if it is thrown out at a high speed it becomes very difficult for the men to catch it. During these passes, while the actual power taken may be large, the time of the pass is short, so that the amount of energy consumed is comparatively small and the flywheel does not

have to give up much stored energy, and so the speed of the mill is maintained practically at full speed.

In the latter passes where the bar has become elongated to a considerable length, the time taken by the pass is considerable—half a minute or so—and while the power may not be very great the amount of energy consumed is considerable, and the flywheel will

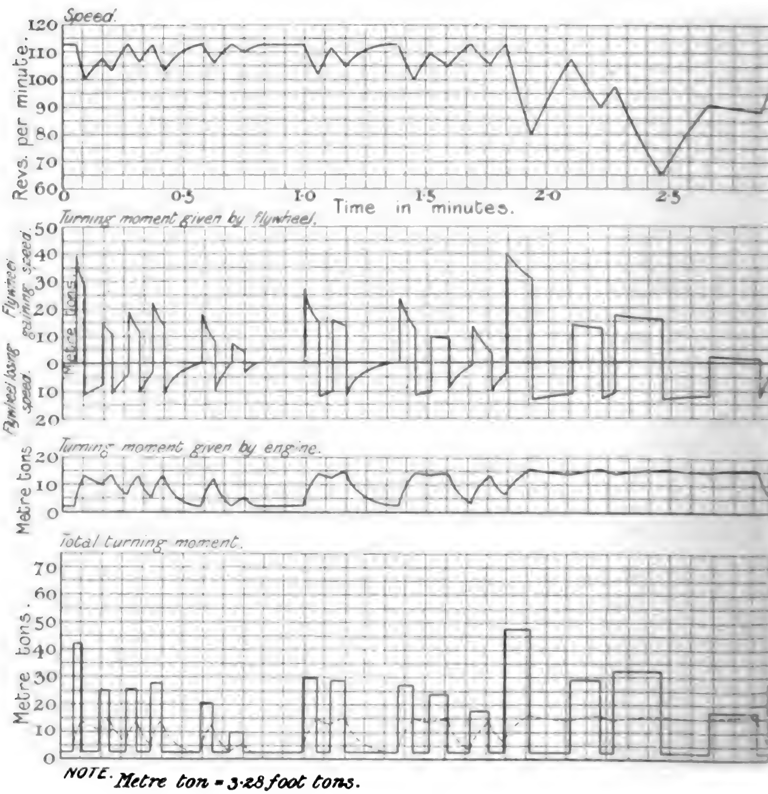


FIG. 15.—Curve showing Tests on a Steam-driven Mill showing the Fall in Speed during the Finishing Passes.

have to vary considerably in speed to give up the necessary amount of stored energy.

In these last passes, where high speed is most desirable to get the bar through the rolls quickly on account of its great length, the speed of the motor has fallen to the lowest limit, and this causes the reduction of the tonnage which it is possible to roll. The reduction of tonnage due to this cause is more marked where the mill is engine driven than where it is motor driven, as is illustrated by Fig. 15.

To overcome this difficulty several steel works have adopted the

Ilgner system for driving large 3-high mills—that is to say, the same type of electrical plant is used which is generally employed for driving reversing rolling mills. In this system the flywheel is not coupled to the mill, but is coupled to a motor-generator set which supplies current to the mill motor. As the mill motor runs at a constant speed whatever power it is required to give, there is no reduction in tonnage owing to reduction in speed in the mill, but the motor-generator set, instead of the rolling mill motor, varies in speed so that the flywheel can give up its stored energy when the power demand is great, and absorb energy when the demand is small, so as to reduce the variation in power taken from the supply system to a reasonable value.

In such a case the motor driving the motor-generator set and the flywheel show variations of speed and power similar to those described in the earlier part of this paper for a mill motor and flywheel, except that in this case the variations in power are very much reduced; partly because the motor-generator set runs at a comparatively high speed, so that the stored energy of the flywheel is very much increased, although its weight and cost may be much reduced, and partly because a much larger variation in speed is permissible, as there is no fear of reducing the tonnage of the mill by allowing the variations in speed to be too great, so that a much greater proportion of the stored energy of the flywheel can be utilised to reduce power variations.

It is obvious that by regulating the field current of the generator of the motor-generator set, the voltage of this machine may be varied, causing the speed of the mill motor to increase or decrease correspondingly, and as there is no flywheel coupled to the mill motor the speed of the mill motor may be increased or decreased very rapidly. In rolling down a billet or bloom, therefore, it is possible to drive the mill at such a speed that while the first passes are being made the billet can easily be caught, and then to increase the speed considerably for later passes where the billet has been rolled into a long bar, and where each pass takes a considerable time, so that the times of these long passes can be reduced.

In this way the total time for rolling down each billet can be reduced, and the tonnage can be increased. The time taken by these later passes can still further be reduced by increasing the speed after the bar has entered the rolls and then decreasing the speed again before the bar leaves the rolls, so that it is not thrown out at too high a speed.

By using the Ilgner system, therefore, the possible output from the mill can be increased beyond that which may be obtained if the mill motor were driven at a constant speed.

The capital cost of the electrical plant for the Ilgner system of driving is considerably more than that of a plain motor and flywheel, but as the cost of the electrical plant is small in comparison with that of the mill and its various accessories, the use of the Ilgner system for driving such a 3-high mill may not increase the total capital cost of the

plant much. As this increase in capital cost enables a much larger output to be obtained, the use of the Ilgner system in such a case cheapens the cost of production by reducing the capital charges per ton rolled.

The use of the Ilgner system increases the losses of power taking place in the electrical machines per day, because there are the electrical losses in the motor and the generator of the motor-generator set to be considered as well as those in the mill motor itself, but as a larger tonnage is being rolled in the day, and the bars are rolled so rapidly that they have not time to cool much, the units of electricity per ton rolled may be actually decreased in spite of this additional loss of power which is introduced.

Where the Ilgner system is adopted, it is always possible to use the mill as a reversing mill if a section has to be rolled which is difficult to manage in a 3-high mill.

The Ilgner system has been adopted up to the present for driving:—

1. 34½-in. three-high mill having three stands of rolls and rolling heavy beams, driven by a direct-coupled motor of 12,600-H.P. normal output. The maximum speed of the motors is 180 revs. per minute, and the speed at which the maximum turning moment is given is 70 revs. per minute. The flywheel motor-generator set, which is provided with a 55-ton flywheel, runs at a maximum speed of 428 revs. per minute, and is driven by a 2,600-H.P. motor.

2. 29½-in. mill having three stands of rolls and rolling beams and light rails, driven by a direct-coupled motor of 8,400-H.P. normal output. The maximum speed of the motor is 180 revs. per minute, and the speed at which maximum turning moment is given is 62 revs. per minute. The flywheel motor-generator set, which is provided with a 55-ton flywheel, runs at a maximum speed of 428 revs. per minute, and is driven by a 1,500-H.P. motor.

3. 29½-in. mill having five stands of rolls and rolling beams and rails, driven by a direct-coupled motor of 7,300-H.P. normal output. The maximum speed of the motor is 180 revs. per minute, and the speed at which maximum turning moment is given is 52 revs. per minute. The flywheel motor-generator set, which is provided with a 75-ton flywheel, runs at a maximum speed of 428 revs. per minute. This three-high mill motor is supplied from a generator attached to a flywheel motor-generator set, which is supplying an electrically driven reversing rolling mill at the same works.

4. 23½-in. mill having three stands of rolls and rolling rails, beams, and sections, driven by a direct-coupled motor of 6,000-H.P. normal output. The maximum speed of the motor is 180 revs. per minute, and the speed at which maximum turning moment is given is 140 revs. per minute. The flywheel motor-generator set, which is provided with a 50-ton flywheel, runs at a maximum speed of 500 revs. per minute, and is driven by a motor of about 1,200 H.P.

5. 22-in. three-high mill having three stands of rolls and rolling rails,

sections, and rounds, driven by a direct-coupled motor of 2,400-H.P. normal output. The speed at which maximum turning moment is given is 120 revs. per minute, and the motor is arranged to run at very considerably higher speeds with a correspondingly less turning moment. This three-high mill motor is supplied with power from a generator attached to a flywheel motor-generator set which supplied a large reversing mill in the same works.

6. 20½-in. three-high roughing mill, rolling billets, driven by a direct-coupled motor of 3,800 H.P. The maximum speed of the motor is 180 revs. per minute, and the speed at which maximum turning moment is given is 100 revs. per minute. This three-high mill motor is supplied with current from a generator coupled to a flywheel motor-generator set which supplies a large reversing rolling mill in the same works.

There is also a seventh three-high mill which is driven on the Ilgner system, of which no particulars are available.

Three-phase Current for Merchant Mill Driving.

The roughing rolls of a merchant mill should be run at the highest speed at which it is found practicable for the men to catch the comparatively short billet, and as in most cases about the same size of billet is being rolled the speed should remain constant.

The finishing rolls, on the contrary, should be capable of running at a large number of different speeds according to the shape and weight of section being rolled.

Light sections which cool rapidly must be rolled at a high speed so as to finish them while hot, but with heavier sections the rate of cooling is slower, so that there is not the necessity for rolling at a high speed, while there is the advantage that better material is obtained if the speed of rolling is lower.

The slowest speed is required for "hand rounds" where the roller has to guide a bar of oval section with his tongs through a round hole, so that the biggest diameter of the oval stands upright, and unless the speed is low the roller cannot follow up the bar.

If the roughing and finishing mills are coupled together and driven by one motor, it will not be possible to run at a sufficiently high speed for the light sections on account of the roughing mill, so that the roughing mill will restrict the output of light sections, while, on the other hand, when rolling "hand rounds" the low speed of the finishing mill will require that the roughing mill also go at a low speed and the output be also restricted. With such a mill the proper outputs can only be obtained at the medium speeds.

The ideal drive, therefore, is to provide a constant-speed motor for the roughing mill and a separate variable-speed motor for the finishing mill, and when this is done the roughing mill is usually placed in tandem with the finishing mill.

Where the power available is direct current, this arrangement

presents no difficulty, but where 3-phase current must be used, the means of providing a variable-speed drive for the finishing mill needs some consideration.

The simplest arrangement would be to provide an ordinary 3-phase motor, and to reduce its speed when required by inserting resistances in the rotor circuit. This entails such a large waste of power in the resistances when the lower speeds are required that the arrangement is not practicable commercially. In addition, when the power diminishes in the interval between passes or in the interval between the finishing of one billet and entering the next, the speed tends to increase up to the maximum speed, so that when the next billet is entered, it is very difficult to handle the material.

Another arrangement which can only be used where a rope drive can be employed is to provide an ordinary 3-phase motor having three rope pulleys of different sizes on its shaft, and to change the ropes from one pulley to another when different speeds are required for the mill.

To enable this to be done the motor bedplate has to be made to slide in two directions, so that any one of the three pulleys can be brought opposite the main rope pulley which is coupled to the mill, and so that the motor can be slid away from this pulley in order to tighten the ropes.

This arrangement only enables three possible speeds to be obtained, which is insufficient to meet most requirements, and it has also proved itself to be very wasteful in power, and on this account it cannot be considered where economy is any object.

Another arrangement which is much more satisfactory is to convert the 3-phase current to direct current, and then to provide a direct-current rolling mill motor, so that the speed can be varied to any required speed in order to suit all conditions without wasting any power, and with the exception of that variation in speed which is necessary to enable the flywheel to give up and regain part of its stored energy the speed remains constant at the required value.

As the 3-phase current must be converted to direct current, a transformer and a rotary converter would be needed for this purpose, so that the capital cost of the plant is increased, and there is a certain loss of power in converting from 3-phase current to direct current.

This loss of power in conversion, however, is very small compared with the losses of power in the two arrangements mentioned above, while the extra capital cost is fully justified by this saving in power.

A still more economical arrangement for obtaining variable speed has been adopted for three merchant mills in this country (Fig. 16). This consists of employing a 3-phase motor direct coupled to a direct-current motor for driving the mill. A rotary converter is connected to the rotor circuit of the 3-phase motor, so that when the set is run at reduced speed the power which would otherwise be wasted in resistances in the rotor circuit is converted by the rotary converter from 3-phase to direct current, and then used usefully to supply the direct-current motor.

Comparing this scheme with that of converting all the 3-phase power to direct current and installing a direct-current rolling mill motor, it should be pointed out that in this latter scheme the rotary converter and the direct-current motor do not have to deal with the entire power, but with a power proportional to the amount that the main 3-phase motor is running below synchronous speed.

The conversion losses are therefore reckoned on a fraction of the power, and not of the entire power, so that the arrangement is much more efficient. Further, the rotary converter and the direct-current motor are proportioned for a fraction of the power instead of the whole

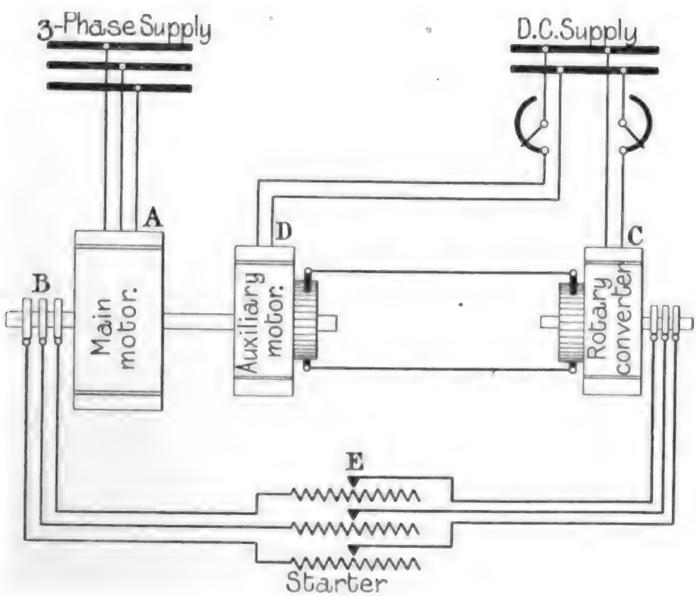


Fig. 16.—Diagram of Connections of High-efficiency Variable-speed 3-phase Rolling Mill Motor Set.

power, so that they can be small machines. The arrangement therefore is cheaper in capital cost.

With this arrangement the direct-current motor is provided with a compound winding to act as a continuous-slip regulator, and the combination behaves like an ordinary compound-wound direct-current motor, the speed being varied by altering the resistance of the shunt field circuit of the direct-current motor, while with the exception of that variation in speed necessary to enable the flywheel to give up and regain part of its stored energy, the mill motor set runs at the required speed and does not give trouble by attempting to increase in speed up to the maximum speed between the passes.

Generally speaking, where there is a choice between direct current or 3-phase for driving a mill for which variable speed is desirable and there is little or no difference in the cost of current, the adoption of direct current will be found the most economical.

Friction Losses.

Particular care should be taken to reduce as much as possible the friction losses, or other such losses which have a constant steady value independent of the power which the rolling mill may be giving, because, generally speaking, the power taken by a motor driving a rolling mill varies between wide limits, so that the average power taken is very much less than the rated output of the motor, and any losses such as those due to friction which go on continuously very considerably increase the number of units of electricity used in a given time.

This is a point which is very liable to be overlooked, because such losses are usually stated as a percentage of the rated output of the motor and so appear small, but if the average power of a rolling mill motor is one-third of its rated output, as is often the case, a friction loss which may be only 10 per cent. of the rated output will increase the total units consumed in a given time by 30 per cent. Such friction losses may be caused by the friction in the flywheel bearings, or by the windage of the flywheel itself, or in the drive used to transmit the power of the motor to the mill in those cases where the mill motor is not direct coupled.

These remarks apply particularly to rope drives when used for rolling mills, as it is usually stated that a rope drive involves 10 per cent. loss of power, but this only applies to the case of a motor which is constantly transmitting its full power through the rope drive.

It would be much more exact if the statement were made that the use of a rope drive involves a loss of 10 per cent. of the power which the ropes are capable of transmitting normally, and that this loss remains constant whether the motor is giving its full normal output or not.

To take a practical example, the case of some tin-plate mills may be considered which require a 450-H.P. motor, where the power varies between very considerable limits, and where there is a choice between installing a high-speed motor driving the mills through a rope drive or installing a slow-speed motor direct coupled to the mill.

It may be assumed that the loss in the rope drive is 10 per cent. of the full-load power of the motor, that the efficiency of the slow-speed motor is 2 per cent. less than that of a high-speed motor, and that the actual power consumption required by the mill apart from the drive is 15,000 units per week. If a slow-speed motor be installed, 2 per cent. must be added to the 15,000 units on account of the low efficiency, so that the units consumed in the week will be 15,300.

If the 450-B.H.P. motor ran steadily at its full power, making due allowance for 5 per cent. loss in slip resistance, etc., the steady input would be 385 k.w.; therefore if the motor ran steadily at its full power for a week of 120 working hours it would consume 45,000 units. Ten

per cent. of this, or 4,500 units, are wasted in the rope drive, so that if the high-speed motor with the rope drive be installed, the total units consumed per week will be 19,500, or 4,200 more than if a slow-speed motor be used.

Supposing that the cost of power is 0·5d. per unit, the extra 4,200 units used per week will cost £8 15s., or £437 10s. per annum. This saving would justify a very considerable extra capital expenditure on a slow-speed motor.

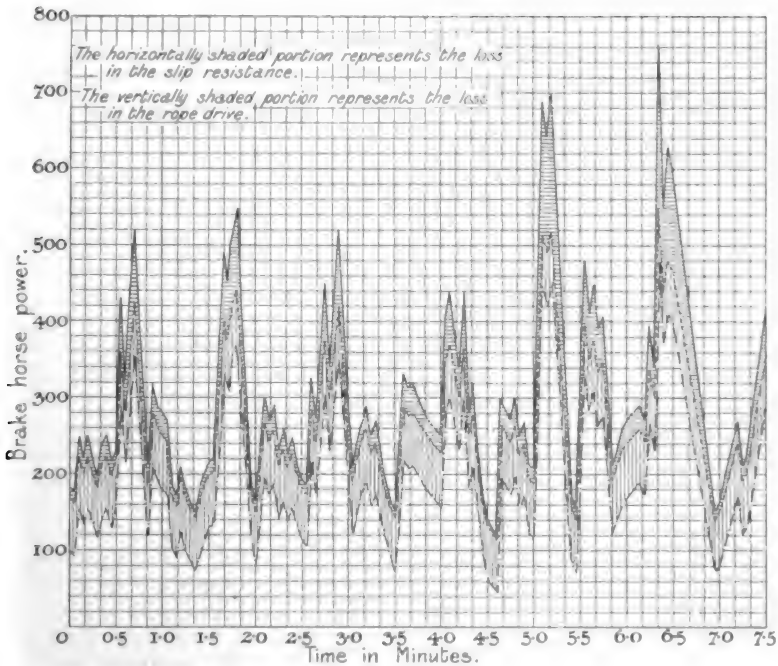


FIG. 17.—Analysis of the Results of Tests on a Sheet Mill, showing the Losses occasioned by the Ropes and the Continuous-slip Regulator.

Fig. 17, which was obtained from tests on a sheet mill, shows the proportion of the total units of electricity used which were consumed by such losses.

While any discussion of the details of construction of rolling mills is outside the scope of this paper, the author holds the opinion that insufficient attention is paid to the question of friction in the pinion housings or on the roll necks, and thinks that improvements might be effected which would reduce this friction, and that any such improvements would materially reduce the cost of rolling.

In many mills the power consumed by the friction of the mill itself is about $\frac{1}{5}$ or $\frac{1}{4}$ of the normal rated output of the motor which is

installed to drive the mill, so that nearly 50 per cent. of the units of electricity used per ton rolled are wasted in friction. This shows how great an opportunity there is for improvements for effecting economies in the cost of rolling.

The foregoing observations regarding the large waste of power caused by rope drives where the friction is independent of the power transmitted does not apply to the same extent to the gear drive, because the pressure between the teeth, and hence a greater part of the friction, is dependent on the amount of power transmitted. When a small power is transmitted the friction loss is reduced, so that with a gear drive the units of electricity consumed on the overcoming friction do not form so large a proportion of the total number of units consumed as with a rope drive.

In certain mills, particularly in brass and copper sheet mills, long trains of gearing are usually used for transmitting the power of the motor to the rolls, and are so arranged that the power for the more distant mills is perhaps transmitted through ten different pairs of gear-wheels. A more wasteful way of applying power could hardly be imagined.

Economy.

The question of electrical driving is seldom raised without comparisons being made between the cost of driving rolling mills by steam or by electricity, but it is outside the scope of this paper to revive this well-worn subject.

Various economies can be effected by the electrical driving when properly applied, but one of the principal economies is that of the cost of power.

The electrical drive often enables cheap power to be used when it could not be transmitted or applied in any other way, and also in many cases it affords a means of enabling power to be generated cheaply, so that in planning an electrical drive every care should be taken to make use of its natural advantages as far as possible.

In a large city where land is expensive, and where facilities for generating power in each individual works are far from the best, it is generally found to be most economical to buy power from the supply authority where the amount required is not very large, because power can be generated in bulk in a power station and distributed to the various works more cheaply than the works can generate themselves.

Where works are not situated in a city, and where the cost of ground, etc., is much less, it is generally found that the works themselves can generate more economically unless the amount of power required is very small.

Where cheap power is available it must be applied as economically as possible, and it will be seen from what has been said in the foregoing that considerable care must be exercised in applying a motor and flywheel to a rolling mill in order to ensure that the power is utilised as cheaply as possible if it is desired to obtain economy in working.

There is much reliable information at present available about the units per ton taken to roll various sections, some of which has been given by the author in other places, so that there is no need to repeat these figures here. Attention should, however, be particularly drawn to the inaccurate results which will be obtained if any attempt is made to arrive at the proper size of the motor by multiplying the units per ton by the tonnage which it is desired to obtain from the mill on the average.

Any such figure which is obtained in this way would be far too small, because a rolling mill always works more or less intermittently, as either it is a physical impossibility for the men to stand up to the work continuously—that is to say, to keep up the maximum rate of rolling at which they could roll one bar, or else the mill has to wait for hot billets from the furnace, for the finished material to be cleared away, for roll changing, or for other reasons.

In conclusion, the author wishes to express his best thanks to the Siemens Companies for the assistance they have given him in the preparation of the paper, and for their permission to publish much of the information contained therein.

Discussion.

Dr. E. Rosenberg: Most of the conclusions to which the author comes are absolutely correct and cannot be contradicted. I would like to discuss only a few points which the author raises. He mentions that in order to make a flywheel act we want a difference in speed. If we use a difference in speed of 10 per cent. we get approximately 20 per cent. of the energy stored in the flywheel. We are not able to get much more with alternating-current induction motors, because the regulation of speed cannot be effected without loss of power; but with direct-current motors we can effect the regulation of speed without losing power by means of series winding. On the other hand, if we use the ordinary compound motor it is not possible to get a very big drop in speed for a comparatively small change in load. In one of the slides shown it was clear that when providing for 20 or 22 per cent. drop of speed from no load to double full load, the speed variations actually occurring during ordinary working are only about half of this percentage. We may say that we should prefer a motor which for a current changing, say from three-quarters average current to $1\frac{1}{2}$ times average current, will produce a slip of approximately 20 per cent., and then we should be able to use about 36 per cent. of the energy stored in the flywheel. With the compound motor this is not possible, because the shunt winding which provides the constant field represents a big portion which cannot be changed. I speak now of the compound motor without an automatic slip regulator. The shunt winding must be strong enough to prevent, without any load on the motor, dangerous speeding-up, and in this case the additional series winding will for a small change in current only give a comparatively small speed drop. Dr. Rosenberg.

Dr. Rosenberg.

In one flywheel set installed I have made it possible to use the characteristics of the series motor, which gives a far bigger speed range for the same range of current, without incurring the danger of the motor running away. I have made a shunt winding, but connected the shunt winding, not to a source of constant voltage, but to an exciter coupled to the flywheel set. The exciter is shunt excited, but also compound or series winding could be used on the exciter. If the speed drops considerably, the exciter nearly loses its voltage; therefore the current in the shunt winding of the flywheel motor will be extraordinarily small, and the motor will act practically like a series motor. If the speed, however, comes very near to the critical speed, to what we call the safe speed limit, then the exciter will pick up rapidly; therefore, also, if the motor takes no current at all the speed is limited to a certain predetermined amount, and even if the voltage of the supply rises above normal, the speed of the flywheel set will rise by a far smaller percentage due to the over-excitation obtained. The same scheme can be used for the motor of the Ilgner flywheel set (see British patent, No. 24,511, of 1910).

I have noticed with great interest in the paper the comparison of the different methods of regulating the speed of merchant mills. The author prefers the arrangement of a rotary converter and direct-current motor in cascade with the main slip-ring motor to the arrangement of a plain rotary converter and only the direct-current motor on the mill. He says that the efficiency is superior. I cannot follow that, and I have figured it out in a few cases. We can make out the superior efficiency on certain assumptions, which, however, very seldom check with the practical requirements. If we have a very small speed variation then our rotary converter and auxiliary direct-current motor are designed for a small output, and the losses in those two machines then are lower than the loss in the transformer and rotary converter of the second scheme (plain direct-current motor). Of course we have in the cascade scheme always the full-load losses of the main slip-ring motor, which has no better efficiency than the direct-current motor in the second case, and we also have, when reducing the speed, additional iron losses in the rotor of the main motor. For small speed variations it is true that the efficiency is slightly better in the cascade system, but if we have speed variations, say, of a ratio of 1 : 1·6 or 1 : 2, or even 1 :3, as mentioned to-night, then the picture changes completely. For high-tension alternating-current mains it is also certainly a drawback of the cascade scheme that a high-voltage alternating-current motor is used on the mill, while in the second case the high-tension exists only in the much safer static transformer. Another disadvantage is also that we have to connect to the rolling mill a combination of two motors, which takes up a lot of space. We have also an additional set of slip-rings on the main motor, and, what I regard as the most disagreeable feature of the whole system, we want a direct-current supply. The direct-current supply may be available in the works for lighting, but it means that the working of our rolling mill is not only dependent

Dr. Rosenberg.

upon one but upon two sets of supply mains. If the direct current is not available from another source, we must have a motor-generator for supplying the current for excitation of the direct-current motor and rotary converter, because the exciter could not be coupled to any one of these sets which are running at such variable speeds. One thing is not clear to me. If it is suggested to get a continuous speed range from 100 per cent. of full speed down to, say, 50 per cent., then running at, say, 95 per cent. speed, or still nearer the full speed, the periodicity of the slip-ring currents is extraordinarily low, and the rotary converter would run at a dead slow speed. The copper losses in field and armature of the rotary converter will be equal to the full-load copper losses. Therefore if we try to run the set for a very long time at such a speed the rotary would have a tendency to burn out, and we could only overcome this by supplying a ventilating plant, say a large-sized fan, perhaps coupled to the exciter motor-generator, and driving a continuous air-blast through the rotary converter. I would ask for information whether this has been done in existing installations.

Dr. Wiesengrund.

Dr. B. WIESENGRUND: The general conclusions the author has arrived at are hardly controversial. One of his principles appears to be that the outfit of an electrical rolling mill should be so chosen that what I would call the overall economy of the plant should be a maximum. The maximum overall economy would be reached when the combined total capital charges and running charges becomes a minimum. The author appears on the whole to regard as a standard arrangement the direct coupling of the motor to the rolling mill shaft, at least the direct coupling of the flywheel to the rolling mill, where he does not recommend the "Ilgner system." Intermediate mechanical means for the purpose of transmitting the motor-power to the mill, the author almost appears reluctant to mention at all, as he merely refers to them under the head of friction losses. Doubtless the author is perfectly correct that for rope drives the average losses are high. The rope drive is a friction drive, and as such it must be so arranged from the start that it is capable of transmitting the maximum power which has to pass it, and, at least without very great complications, it is not possible to adjust the friction to different load conditions, and therefore the losses will always correspond to the maximum load. The author mentioned in the paper that the case for gear drives was not quite as unfavourable as for rope drives, in so far as the loss in the gear varies with the load. I believe the author has not done entire justice to the gear drive by this bare admission. I can conceive a great many cases in which the maximum economy at which the author aims is more easily obtained by the introduction of gearing than by the direct coupling of the motor to the rolling mill shaft. This must certainly be the case if it is a question of mills running at comparatively low speeds, say, 30 to 35 revolutions, such as the author has mentioned.

Fig. A represents a rolling mill equipment consisting of a 3-phase slip-ring motor of 300 H.P., with a maximum overload capacity of 600 H.P. running at 350 revs. per minute, coupled by means of flexible

Dr. Wiesengrund.

coupling to a shaft carrying a cast-steel flywheel about 8 ft. in diameter with an approximate weight of 5 tons, the flywheel shaft at the other side to the pinion of self-contained double helical reduction gear reducing in one step the speed from 350 to 35 revs. per minute. The shaft carrying the double helical wheel is made with wobbler end for direct coupling to the mill shaft. A slip regulator is provided by means of which the motor speed can be reduced 10 per cent. below its normal full-load speed. The centre distance of the gear is about 46 in., its face width 24 in. The feature of the arrangement is, of course, the arrangement of the flywheel between motor and gear, so that the latter has not only to transmit the motor-power, but also the

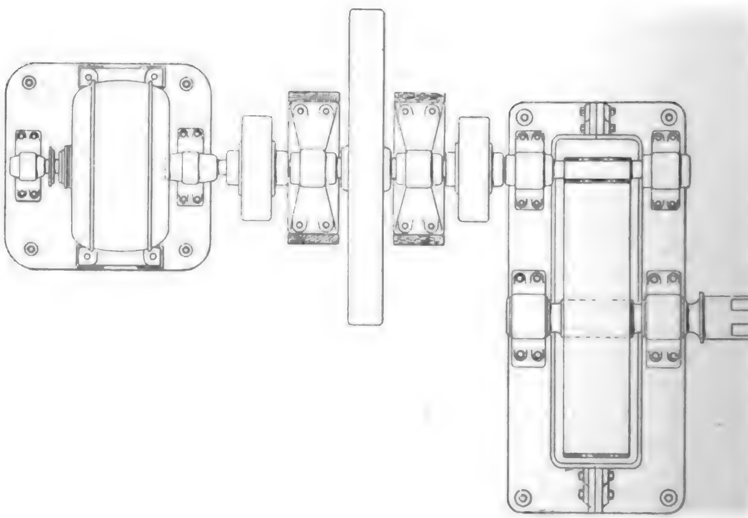


FIG. A.

energy given off by the flywheel. This naturally necessitates a larger gear than would be required with a flywheel on the low-speed shaft, but the increase in the gear dimensions is not very considerable because in the first instance such high-ratio reducing gears have to be dimensioned for wear, so that their safety factor with regard to strength is very considerable. The distribution of the load over a large number of teeth, and the gradual progress of the engagement without any shocks, enable this type of gear to withstand overloads which would be detrimental to straight-cut gearing. The author will probably admit that at least for mills with powers between 300 and 1,500 H.P., the combination of a high-speed motor, high-speed flywheel, and high-ratio reduction gear will, in regard to first cost, be very superior to the direct-coupled motor. The author has made a very strong point that the friction losses should be kept as low as possible. I believe that in

this respect the arrangement shown cannot be surpassed. The friction losses in the flywheel bearings must be very much less in a flywheel weighing only about 5 tons than in a flywheel weighing about 50 tons, and this will probably be the proportion of the weights for the same energy of flywheels at 35 and 350 revs. per minute respectively. The permanent loss in the gearing is extremely small. With gearing similar to the one I have shown, full-load efficiencies as much as 99 per cent. have been obtained. The bearing losses are naturally constant. On the other hand, the efficiency of the high-speed motor is considerably higher than the efficiency of the low-speed motor. I notice that the author in one portion of his paper estimates the superiority of the high-speed motor in efficiency over the low-speed motor at about 2 per cent. The author probably means in this case the full-load efficiency. Most of the losses in the low-speed motor will, however, remain constant whatever its load. Therefore the mean efficiency of the low-speed motor should be somewhat considerably less than that of the high-speed motor. Dr. Wiesengrund.

Mr. C. HOWARD: In reference to the author's remarks on friction, I would like to ask him whether he has ever tried to decrease the friction in tinplate mills by using one pair of rollers only for the roughing and for the finishing. That is the system followed in America, and it enables the output to be doubled in the same shift. It reduces the friction by one-half if there is one pair of rolls instead of two, and enables the output to be doubled, and so increases the overall efficiency very much. With the rest of the paper I am in perfect agreement as regards its application to tinplate mills, with which I have had experience which has extended during the past year over twelve electrically driven tinplate mills. Mr. Howard

Communicated: Referring to Mr. R. Borlase Matthews' criticism of the American system of rolling tinplates and his contention that Welsh tinplates command a higher price than those manufactured in America, it may be well to point out that recently large orders for tinplates for the oil trade have been placed with American manufacturers, and great difficulty is experienced in securing Canadian and American orders which have hitherto been awarded to Welsh manufacturers. One great disadvantage often urged against the American system is that the rolls become overheated and do not last so well throughout the week, besides resulting in a larger number of broken rolls. This is probably quite true if the output is pushed beyond reasonable limits, but no difficulty in this direction should be encountered providing the output is limited to, say, 110 to 120 boxes per shift. The average output on the Welsh system is about 55 to 60 boxes per shift. Again, in the Welsh system of rolling, the roughing and finishing rolls are alternately heated and cooled according to the stage of the work, *i.e.*, the roughing rolls are heated whilst the thick iron is being passed through, and are cooling whilst the sheets are being rolled in the finishing pair of rolls. Now if one pair of rolls is used for both processes within the limits given above, a fairly uniform temperature of the rolls should be

Mr. Howard.

secured with a consequent prolongation of the life of the rolls. Finally, in determining the quality of the finished sheet, it should be noted that the finishing processes have quite a definite influence on the result, and, as a matter of fact, a number of boxes recently rolled on the American system in a Welsh mill presented no discernible difference from those produced by the regular Welsh method. It may be said that a large proportion of the newest mills installed in South Wales have their roll standards mounted in the American fashion, and it is quite legitimate to assume that a trial might be given with advantage to other methods adopted by our competitors. In order to follow the arguments used above I append a description of both Welsh and American systems of rolling sheets for manufacture into tinplates. The tinplates are rolled down from bars varying in weight and length according to the size of plate required. Such a bar is generally referred to as the "pack" or "thick iron," and the weight of the pack under the Welsh system is practically twice that under the American system, owing to the American practice of rolling two singles together as doubles.

Welsh Method.—In this system two pairs of rolls are used, one for rolling down the thick iron bars, and the other pair for rolling the sheets. The number of men per mill per shift is generally four, viz., one rollerman, one furnaceman, one doubler, and one behinder, or catcher. It is the furnaceman's duty to see that all the bars and sheets are of the proper temperature at the right time, and to hand them out to the rollerman. The rollerman puts the bars and sheets through the rolls and they are caught by the behinder and passed back by him over the rolls to the rollerman, who adjusts the screws over the top roll so that the necessary elongation is produced. After the thick iron has passed through the rolls it is passed back to the furnaceman in the form of "singles"—*i.e*, single sheets—who reheats it for the next process. It will be noticed that the doubler is idle during this process. The "singles" are then rolled out to practically double their present length, and passed over to the doubler who bends the plate double and squeezes the fold flat under a press, and also cuts the ends square, after which the double sheet is passed back to the furnaceman for re-insertion in the furnace. This process is repeated with the "doubles" and "fours," but in the final process, viz., rolling the "eights," which is generally the finishing process, the sheets are not passed to the doubler but are stacked by the behinder in some position convenient to himself, and they are then ready to be "sheared" and "opened." It should be borne in mind that the rollerman when rolling "doubles" and "fours" has also to separate the sheets before passing them on to the doubler, who, it will be noted, is practically idle in the first and last stages of the process. Between the eights of one heat and the thick iron of the next there is generally a break of 5 to 20 minutes whilst the men are resting or eating, and a careful analysis of the working period shows that the average time that each mill is working does not exceed 70 per cent. of the length of the shift.

American Method.—Nine men form a shift for each mill in this

Mr. Howard.

system, classified as follows :—(1) Rollerman (in charge); (2) assistant rollerman, or rougher; (3) and (4) two furnacemen; (5) pair heater; (6) doubler; (7) and (8) two behinders, or catchers; (9) screw boy. The first part of the heat is the roughing down of the bars in the following manner: (1) The pair heater transfers the bars, two at a time, to the rougher, who with one behinder passes them through the rolls whilst the screw boy attends to the screws, after which the plates are replaced in the finishing furnace by another of the furnacemen. (2) Immediately after all the bars are roughed down the rollerman takes the place of the rougher and the work proceeds somewhat on the Welsh

Process.	Men Working.	Men Resting.	Pair Heater.
Thick iron	One furnaceman Rougher ... One behinder ... Screw boy ...	One furnaceman Rollerman ... One behinder ... Doubler ...	Working
Doubles ...	Rollerman ... One furnaceman One behinder ... Doubler ... Screw boy ...	Rougher ... One furnaceman One behinder ...	Charging furnace with thick iron
Fours ...	Rougher ... One furnaceman One behinder ... Doubler ... Screw boy ...	Rollerman ... One furnaceman One behinder ...	Watching furnace and resting
Eights ...	Rollerman ... One furnaceman One behinder ...	Rougher ... One furnaceman One behinder ... Doubler ... Screw boy ...	As in fours

method, except that the sheets are generally worked two at a time, and the screw boy, not the rollerman, opens up the "pack" after it is thrown down from the rolls. (3) The rougher again takes up his station after completion of process (2), and the "fours" are now rolled on the same lines as in process (2), the screw boy separating the top and bottom sheets. (4) The "eights" are now rolled with the rollerman at the rolls, and this process is practically the same as the Welsh method. From the table above it is easy to see that there is ample time for all hands at the mill to recuperate between such periods as they are called upon to work, and no time is lost between the "eights" of one heat and the thick iron of the next heat, such as is noted in the Welsh system.

Mr. Matthews.

Mr. R. BORLASE MATTHEWS: A feature of this paper is that it deals with a number of practical points upon which it is usually very difficult to get any reliable information. The author very wisely avoids any discussion as to the comparative cost of the operation of steel rolling mills by steam as compared with electric drive, and really the matter has got past the stage where comparison is needed, for in this country between 80,000 and 90,000 H.P. is now utilised for operating rolling mills alone—a very considerable figure, which indicates the faith of steelmakers in the economy and advantage of the electric drive. I have been more particularly interested in the driving of tinplate sheet mills and tinplate bar rolling mills, which present, perhaps, some of the more difficult problems in rolling mill driving, on account of the frequency of the passes and the varying nature of this special work. With the electric drive in a tinplate mill a plant is available which is capable of an output in advance of the physical endurance of the men, and really the mill has to be cut down to what the men can do, rather than limited by the actual maximum capacity of the system of driving. With reference to Mr. Howard's comments, I do not think South Wales tinplate manufacturers would agree very much with American practice. South Wales tinplates can sell against American tinplates any day, with a considerable margin in their favour on the score of their greatly superior quality. Separate rolls for roughing and finishing give a very much better product, for which an additional price can be obtained that more than compensates for any friction loss entailed by the extra mill. Certainly, as referred to at the end of the paper, the question of friction loss in mills is a very important one, to which comparatively little attention has been given. On the electrical side the efficiency has been brought to a high pitch of perfection, but on the mechanical side there still remains a very great deal to be done which would greatly reduce the cost of operation under ordinary conditions. The first curve that the author exhibited on the screen showed the very excellent results that can be obtained from a properly designed electrical drive. Referring to the question of the regulators, in addition to the advantages that the author points out, that are in favour of continuous slip regulators, there is also the minor one that this method is a little less complicated so far as the men are concerned who have to maintain and keep the equipment in order. I think the author rather assumes that the losses due to rope drive are a little greater than they really are. It has proved a very useful drive notwithstanding any slight disadvantages that it has, and it certainly makes a very smooth drive. The author is apparently very much more in favour of the use of direct-current motors than of induction motors for rolling mill work. American practice, on the other hand, seems to be rather in favour of the use of induction motors. It would be very interesting if the author would let us know what he has done to improve the power factor in the cases where he has employed induction motors. Considerable trouble has been experienced in this particular direction, and one method adopted to overcome it, in the case of some steel mill drives, is to employ synchronous motors

on other loads in the works, such as rotary pumps, blowers, washers, and any other possible machines. In one particular case, which happened to be a large American mill, the power factor was so bad that a 5,000-k.v.a. rotary condenser had to be installed. Mr. Matthews.

Mr. J. J. FASOLA: Referring to the theoretical diagrams 5, 6, 7, and 8, the author has shown that the 3-phase permanent slip losses were something more than one-third of the losses in one case, and I think this is where improvement should be introduced if possible. A motor designed for increased copper losses to give a larger inherent slip could have its iron losses reduced, thereby compensating for part of the slip losses. In the diagrams the power of the motor is referred to as motor-power. I do not know whether this means motor input or output; I presume it means motor output, in which case I think the percentage variation in the average power supply would be something like 7 to 10 per cent. greater than the figure given in the table on account of the losses in the permanent slip regulator. Since the greatest slip losses will occur at the point of maximum output of the motor, and the absolute value of the slip will be greatest in the case of the arrangement with the lightest flywheel, this will increase the R.M.S. value of the stator current more than for the arrangement with the heavy flywheel. The rating of the motor with the light flywheel should, I think, be about 15 to 17 per cent. higher instead of 10 per cent. higher than the motor with the 50-ton flywheel, assuming the diagrams are for motor output. To enable these curves to be investigated more closely, perhaps the author will give us the radii of gyration and concentrated masses of the flywheels and the exact synchronous speed of the motors on which the diagrams are based. I think from the remarks that have been made it is desirable to keep on the high side with the weight of the flywheel on account of these slip-regulator losses. Of course there are limitations, because the flywheel effect on the reduction of variation of the power decreases rapidly as the weight of the flywheel increases and the friction losses become large. Mr. R. Borlase Matthews mentioned that the paper seemed to favour continuous current rather than 3-phase, and asked what could be done to improve the power factor. It seems possible to obtain economies by using cascade motors, as they would improve the power factor very considerably at low speeds. In the case of such mills as those referred to under the part of the paper dealing with the Ilgner system where variable speed is required, economies can be introduced at low prime cost by adopting a motor which would run economically at full torque at two-thirds speed for the first passes to enable the men to catch the billet, and would be speeded up to top speed without disconnecting the stator for the last passes, as this would considerably increase the tonnage turned out. It could be provided with a direct-coupled flywheel and slip regulator, or with rheostatic control; it would have the same high overload capacity at both speeds, and it would have a higher power factor than the ordinary induction motor. The power factor seems to be a very important point when comparing a direct drive with a rope Mr. Fasola.

Mr. Fasola. drive or a gear drive, as the power factor of these very slow-speed motors is admitted to be relatively very low. For this reason alone I think there may even be occasion to use a single-speed cascade motor with squirrel-cage rotor, and starter and slip regulator connected across the stator tappings, and direct-coupled flywheel where necessary. To obtain the same speed it is obviously cheaper to build a cascade motor with a 40-pole stator and a 20-pole short-circuited rotor than an ordinary induction motor with a 60-pole stator and a 60-pole slip-ring rotor. On account of the design of the single-phase speed cascade motor on the Hunt single-winding system, the power factor is considerably higher. For merchant mills there might often be an application for 3-speed motors running at full speed, half speed, and one-third speed. They would run economically at these speeds, and the prime cost would be considerably less than introducing rotary converters and converting into direct current.

Mr. Allingham. Mr. G. C. ALLINGHAM: The author has referred only to one method of equalising the power demand of rolling mills, namely, by means of flywheels, but there is another well-known method of equalising fluctuating power loads, and that is by the aid of storage batteries, with or without automatic reversible boosters. It is true that, in the case of a single large rolling mill a storage battery could hardly compete as an equaliser with a flywheel, because its first cost would be excessive; but in the case of a works containing a number of rolling mills of moderate size there is a good deal to be said for providing a single common equalising device, instead of a separate equalising device on each of the mills, in this way taking advantage of the diversity factor. On the other hand, where a single equalising device common to a number of motors is employed, a flywheel is, in general, unsuitable, because the total power load of the motors fluctuates in a manner which is quite irregular. Generally speaking, the flywheel equaliser is particularly suited for cases where successive fluctuations of load follow one another in a cycle which repeats itself with more or less regularity. The flywheel can then be so designed that it is just capable of taking one of the peaks, and of being speeded up in the valley intervening between two successive peaks. But where the load is irregular—for instance, where there are a number of rolling mills, each of which is probably working more or less irregularly—there may at one time be a period when the total load for a considerable time is above the average, or when a rapid succession of peaks slows the flywheel down without giving it a chance to speed up between, followed by a period during which the load is below the average, and when the flywheel, having been speeded up to the maximum, goes on running for some time doing nothing but churning the air and wasting electrical energy. For dealing with an irregular load of this description a flywheel has these drawbacks: first, its capacity for storage of energy is very small; and secondly, its no-load or fixed losses are great. An additional drawback is that, whenever the flywheel is stopped (*e.g.*, at times of light or no load), all the energy stored in it is thrown away, and a corresponding amount of energy has

to be supplied whenever it is necessary to start it up again. Storage batteries are free from all these objections, and are capable of dealing with an irregularly varying load of this description without difficulty. The storage battery has other incidental advantages which are of importance in some cases; it forms a standby in case of temporary breakdown, and may also be useful for providing a supply of light or power at times when the generating plant is shut down, for working overtime, or for other purposes. I believe there is a considerable field of usefulness for the adoption of storage batteries, especially in works where there are several rolling mills of moderate or even of considerable size. Mr. Allingham.

It is often supposed that the storage battery is inapplicable where the power supply is 3-phase, but this is by no means the case. A battery can be used economically and satisfactorily in conjunction with a reversible motor-generator or rotary converter, and there are several instances of batteries having been used in this way quite successfully. It is true that the losses in the battery and its auxiliary plant are greater in such a case than with a direct-current supply, but they are by no means prohibitive, especially if a rotary converter is employed, the necessary variation of the voltage on the direct-current side being obtained by means of either split poles on the converter or an alternating-current booster on the 3-phase side of the converter.

A point worth considering is the very serious amount of energy wasted in the slip resistances, with flywheel equalisers—at least where 3-phase motors are employed. The author mentioned in one particular instance that the loss was 13·5 per cent., so that the loss may well be of the same order of magnitude as the loss in the storage battery. The author considers that automatic slip regulators are not of much use for rolling mills because they do not act quickly enough; but it seems that there might possibly be some room for improvement in that respect over the particular devices described in the paper. For instance, in the case of the direct-current automatic slip regulator, described on page 607 and illustrated in Fig. 10, instead of gradually and timidly short-circuiting the resistance in series with the shunt field of the motor by means of a series of relays acting one after the other, why not employ a device somewhat on the principle of the Tirrill regulator, which would short circuit the resistance instantaneously, and would continue to short circuit it intermittently, as required? In some such way a very much more rapid action might be obtained.

Mr. ALAN WILLIAMS: I entirely agree with the author in the view he takes as to the position for the motor or the flywheel. There is no doubt that it ought to be direct on the rolls, and not in some other position, as a speaker has suggested to-night. I have had an opportunity of carrying out some experiments with a rolling mill with a gear drive and with some flywheel effect on the motor shaft, and it is quite obvious that with the severe shocks that are obtained in rolling-mill work, the high-speed shafts and the bearing on such shafts will give endless trouble. The other point on which I am in entire agreement with the author is in regard to the use of direct-current motors on the Mr. Williams.

Mr. Williams.

mill shaft. There are different ways of using them and providing them with direct-current energy. Generally we have to consider a 3-phase supply, but it is questionable whether the best way is the use of a motor-generator. Rotary converters are undoubtedly better if they can be used. Of course the great trouble with the rotary converter is the difficulty in varying the voltage of the direct-current output. A system has been devised recently by Mr. Burge, which forms one of the features of what is known as the C.M.B. system, in which two machines are used, one being a rotary converter direct coupled to a direct-current dynamo. The second dynamo has a reversible field, and it adds its voltage to the rotary converter or deducts it, giving a full range of from double the original voltage down to zero. That voltage is controlled by a potentiometer regulator, and also by demagnetising windings, which give a practically constant current or a regulated current. An arrangement of this sort enables varying speeds to be obtained on the mill shaft by varying the voltage on the terminals of the motor, both by hand and automatically; it does away altogether with slip resistances or series resistances, thus greatly improving the efficiency, particularly at low speeds. Incidentally, by adjusting the excitation of the rotary converter the power factor can be improved, which is a very valuable feature. A further point in connection with the system is that a storage battery, if thought advisable, can be placed in parallel with the direct-current side of the rotary converter and can give out energy on peaks to the motors.

Mr. Mountain.

Mr. W. C. Mountain (*communicated*): There is no doubt that there are many instances in which electric driving for rolling mills can be satisfactorily and economically adopted, but I should be glad if the author could give me some comparative costs of rolling per ton, comparing high-class economical rolling mill engines from which the exhaust steam is used in exhaust steam turbines for driving the auxiliary machinery, compared with rolling by means of electric motors, and in giving the comparison he would state what price per unit he is placing upon the value of the current consumed. On page 620—dealing with friction losses—the author makes the statement that it may be assumed that the loss in the rope drive is 10 per cent. I have personally been connected with several rolling mills where a rope drive has been adopted between the motors and rolls, and I find this system of driving satisfactory and economical. The wear and tear on the ropes is exceedingly small, and my estimate of loss due to friction does not exceed more than 1½ per cent. to 2½ per cent. Of the two instances I refer to, one mill was driven by a motor transmitting up to 900 H.P., and in the other instance the power transmitted frequently rose to 1,200 H.P. In proof of my assertion I may say from some very careful tests taken by me some years ago when driving generators by means of coupled compound horizontal engines with drop-valve gear, over a series of tests I obtained an efficiency between the indicated horsepower of the engine and the electrical output of the generator of 84 per cent., and it is impossible that under such circumstances the

Mr. Mountain.

rope loss can have exceeded more than about 1½ per cent. A moment's reflection upon the author's statement will show that he cannot be correct, and I should like to ask him what would be the effect on ropes if when using a motor of 450 H.P. 45 H.P. was consumed in friction on the ropes? The answer would be that due to friction the ropes would be in flames in a very short time. In a paper entitled the "Transmission of Power by Ropes," read by Mr. E. Kenyon before the South Wales Institute of Engineers,* the following statement was made: "*Frictional Test*—Recent tests taken upon what may be regarded as up-to-date engines by a firm of well-known engineers completely invalidate such excessive computations by providing data which are said to represent a safe estimate for large mill powers of, say, 1,000 horse. To this should be added about 1 per cent. for powers below 500 horse, namely: Engine friction, 8 per cent.; shafting, 12 per cent.; rope, 2½ per cent." I think I cannot do better than refer members to this paper. From a very large experience, extending over nearly 30 years in connection with rope driving, I am satisfied that in very many cases rope drive in connection with electrical work is much more economical and preferable to driving through gear however well made, and I think the friction loss is no greater, if as much.

Mr. Hockley.

Mr. NORMAN HOCKLEY (*communicated*): The author says that an intermittent slip regulator would be an ideal arrangement for equalising the load on the motor, and much better than a continuous slip regulator (*i.e.*, simply providing the motor with a considerable series winding on its field magnets), if it could be arranged to act sufficiently quickly when an overload comes on. I do not think there should be any difficulty in designing an apparatus which would be quicker in its action than the flywheel is to drop its speed. This, I think, is the problem, as the current through the motor armature cannot increase until either the speed drops or the field is weakened. An apparatus dependent on the speed for its working, which would ensure a definite strength of field for each speed, by inserting resistance in the shunt circuit as the speed increased, and taking it out as the speed fell, would ensure a practically constant load on the motor within reasonable limits. Such an arrangement would not only keep a more constant load on the generating plant, but would, as the author has shown, provide full torque on the motor and reduce the interval when speeding up, instead of the gradually decreasing torque, and comparatively long interval, provided by the continuous slip regulator. The continuous slip regulator, it seems to me, is an example of a regulator which cannot possibly act quickly enough, as it never increases the field until after the load has increased. Referring to Fig. 13, it will be noticed that when the power taken by the mill changes from 100 to 600, the power given out by the motor instantaneously changes from 350 to 600, although no drop in speed occurs for about 2 seconds. I think this must be a hypothetical case, as it would appear to show either that the

* *Engineering*, vol. 87, p. 368, 1909.

Mr. Hockley.

regulator is so bad that it actually continued to insert, instead of removing, resistance from the shunt circuit of the motor after the load on the mill increased, or that the motor had a rising speed characteristic, which I think would be a dangerous condition, for a rolling mill motor especially. I suggest that the motor should certainly be compound wound, as the author suggests, or, at any rate, have a falling speed characteristic, and also have a properly designed automatic apparatus for strengthening the shunt field sufficiently, as the speed drops, to keep the back E.M.F. of the motor constant, and so keep constant the power given out by the motor.

Discussion before the Yorkshire Local Section, at Sheffield, on 10th January, 1912.

Mr. Eckmann.

Mr. S. Eckmann: I agree with Mr. Ablett that the term "automatic slip regulator" is misleading, but the same must be said of the suggested name, "intermittent slip regulator." What is regulated is not the slip at all, but the current; a more appropriate name would be "automatic current regulator" if a new name is desirable at all. In the same way the term "permanent slip regulator" is misleading; here neither the slip nor the current are regulated, and it would, perhaps, be better to call the thing what it really is, namely, a "resistance in the secondary." With regard to the following statement in the paper: "Alarm is raised from time to time in cases where work is being carried on very rapidly so that there is only a very short interval between passes, to the effect that the flywheel may not have time to recover itself between the intervals and passes. Such alarm is entirely without foundation, and this is illustrated by Fig. 5." I am of opinion this alarm is well justified; for where the passes are long and the intervals short the motor energy approaches the load on the rolling-mill shaft very closely. The flywheel, therefore, does very little work, and is neither worth the money nor the space nor the additional running costs caused through friction. British firms nowadays build motors which can be connected directly to finishing rolls without the insertion of either a flywheel or even an elastic coupling, and therefore a flywheel is not even necessary for protecting the motor. As to the curves in Figs. 4 to 8 showing the action of the flywheels, these are somewhat misleading, as the horsepower taken by the rolls has been assumed constant during one pass, whereas the horse-power is proportional to the speed. The figures giving the percentage variation of power, therefore, should be read with precaution; especially in Fig. 7 the result will be rather much affected. With regard to the diagram illustrating the action of an automatic slip regulator in practice, I think this regulator must have been of a poor design. The automatic slip regulators which I have tried in practice have responded much more satisfactorily. If we were to study the photograph of the slip regulator given in the paper we should come to the conclusion that both inertia and friction might have been cut down to a much larger extent, and that in that case the

Mr. Eckmann.

results would certainly have been better. However, the reason why automatic slip regulators are not used more frequently lies in quite another direction. The regulator at one time can only be adjusted for a certain average load. Now the average load on a mill is dependent chiefly on the sections rolled, the temperature, and the output of the mill. So when the rollers were working hard they were hampered by a slip regulator. A rolling mill drive should be able to follow the fluctuations of the output. Such a drive is given, for example, by an alternating-current motor with constant resistance in the secondary or by a compound motor. With regard to the statement of the author that the arrangement with 3-phase motor and 3-step pulley has proved to be very wasteful, and cannot be considered where economy is any object, I cannot see why this arrangement should be very wasteful. There is a slip-ring motor with, say, 92 per cent. efficiency at full load, there is a permanent resistance in the motor which brings the efficiency down to about 87 per cent., and there is finally the rope or belt drive. If a belt drive is chosen as being the more efficient of the two, the efficiency at full load will go down to about 84 per cent. This figure does not include the flywheel friction losses. The belt drive naturally involves a certain loss, say 4 per cent., but, on the other hand, a directly coupled motor is a slower-speed motor, and as such is less efficient than a high-speed motor. Taking costs and overall efficiency into account, I believe that the indirect drive is often justified, which is also the reason why it is so often carried out. The 3-step belt drive is, of course, considerably more efficient than the Ilgner system which Mr. Ablett advocates for three-high mills. There is a slip-ring motor with, say, 92 per cent. efficiency; the slip resistance will bring down this efficiency to 87 per cent. (allowing for the generator 92 per cent., and the mill motor 92 per cent.), the overall efficiency will go down 73 per cent., and here again the losses in the Ilgner flywheel have not been taken into account. Careful investigations and actual guarantees given have shown that the two systems, rotary converter with one direct-current mill motor and the Kramer system, are very much alike both as regards efficiency and first cost. The arrangement with rotary converter and one direct-current motor has, of course, the advantage of greater simplicity, as it has only two revolving machines, whereas the Kramer system involves five rotating machines for one mill, namely, the alternating-current motor, the direct-current motor, the rotary converter, and the exciter motor-generator, which, by the by, are not shown in Fig. 16. Another advantage of the system with single direct-current motor and rotary converter is that it requires less space on the mill, and that one rotary can be used for more than one mill. Thus for three mills there will be required four revolving machines, whereas with the Kramer system at least eleven revolving machines are required. A further important advantage of the single direct-current motor and rotary system is that the current taken from the line is always at power factor unity, whereas with the mixed motor system, even if the rotary is designed for sending a leading current into the

Mr. Eckmann.

line, the power factor cannot be kept unity. Besides, the wattless currents are known to heat a rotary converter much more than the watt currents, so there is likely to be trouble on the rotary when it runs at creeping speed, that is, when the mill runs at nearly maximum speed. I would like to ask what provisions are made in the Kramer system in order to obtain good compounding at low speed. For low speeds the terminal voltage of the direct-current rolling-mill motor is high—say, five times higher than when the mills are running at 90 per cent. synchronous speed. The speeds were about ½ synchronous speed, so the shunt field would have to be ten times stronger than at 90 per cent. synchronous speed. The series field therefore would be extremely weak as compared with the shunt field, and the compounding consequently bad. It is, of course, just at the low speeds that good compounding is required, as at low speeds the flywheels are comparatively ineffective. In my opinion the question of efficiency of the electrical drive has been somewhat overrated. It does not matter much whether the electrical drive is 1 or 2 per cent. higher or lower, so long as the overall efficiency of the mill is absolutely dominated by the friction losses in the mill itself and by the output.

Mr. du Pasquier.

Mr. A. du Pasquier: I must take some exceptions to the author's remarks with regard to 3-phase motors rope-driving merchant mills of medium size, arranged with pulleys to give three efficient speeds with motor-operated bed-plate sliding in two directions. I know of mills so operated with highly satisfactory results, and think that many mill managers would disagree with the author when he says three speeds are usually insufficient to meet most requirements in this class of mill. Unquestionably a system of drive giving economic uniform speed control is preferable, if the extra capital outlay to secure it can be justified, but the question of the return on outlay has always to be borne in mind, and if an attractive saving can be shown in the capital outlay necessary, let us say, for such a 3-phase conversion, and only a moderate return, as will often be the case, on the extra capital required to get uniform speed variation, which in many cases, though desirable, is not essential, it will usually be found that mill men will think the extra money could be spent more profitably in other directions. Further, on this subject of merchant mill driving the author is, I think, not correct in his comments on the respective merits of a rotary converter direct-current motor drive, and the system illustrated in the paper, consisting of a 3-phase motor, a direct-current motor, a somewhat special design of rotary converter, and a motor-driven exciter, unless a direct-current supply is available, which is unusual. It is true, of course, that in the first system a transformer may be necessary, whereas against this, in the other system, there is a high-tension alternating-current motor, an additional motor, and, as mentioned previously, usually a motor-driven exciter. On this score alone there would seem to be a considerable advantage on the rotary with direct-current motor side.

The author talks about the rotary converter and direct-current

Mr. du Pasquier.

motor in his system being proportioned for a fraction of the alternating-current motor rating; well, of course, it is a fraction, but a fairly large fraction: such machines must be rated at from $\frac{1}{3}$ to $\frac{1}{2}$ the capacity of the main alternating-current motor according to the speed variation required. Moreover, the machines have to be built on fairly large frames; the direct-current motor must give its full output at the minimum mill speed. This was well brought out in the slide shown of the English McKenna Company's Mill, where the direct-current motor appeared, if anything, larger than the main motor. As regards the rotary converter, this has always to carry the full rotor current of the main motor, even when running at a speed corresponding to, say, 3 per cent. of the supply frequency, which would certainly call for a considerably larger frame than necessary for the actual kilowatt output on account of the heating difficulties. These drawbacks to the system are, of course, accentuated on a 25-$\sim$ supply. We should therefore think, contrary to Mr. Ablett's statement, that as regards first cost the advantage would be every time with the first system.

Dealing with the question of relative efficiency, there is really very little difference. I have recently seen some close calculations of the respective overall efficiencies calculated for the same mill, and find that at normal loads there may be some slight advantage for the system described by the author but not exceeding 3 per cent. as a maximum, whereas at 100 per cent. overload, a not unusual condition, the advantage at all speeds lies with the rotary and direct-current motor drive, but either way there is nothing much in the efficiency difference where one mill only is considered, though no doubt many people would prefer the direct-current motor drive on account of its greater simplicity and fewer running units. As the author stated, however, it is seldom that we have only to consider one mill, and where there are two or more mills to be operated, there is, of course, a very solid advantage with the direct-current motor drive, both in first cost and overall efficiency. The variations in the power taken by the different mills may to a great extent balance one another, and the necessary capacity of the rotary converter be smaller on this account.

Turning to page 620 of the paper, I think the author is rather hard on the rope drive; I see he debits it with a steady 10 per cent. of maximum output loss. I do not know what the rope-makers would say, but can imagine they will be all up in arms. I should certainly not put the loss at this figure myself, and further, it is not, of course, usual to proportion the ropes normally to deal with the maximum output of the mill motor. I also notice that the slow-speed motor in the author's example is not debited with any 5 per cent. slip loss, which is curious, and that the load factor in the year works out at about 70 per cent., which is surely on the high side and, of course, directly affects the economy he claims for the direct drive. Making these corrections, while I think there would certainly be some gain in efficiency for the direct drive, it would usually be nothing like so great as the paper

Mr. du Pasquier. claims to show. A further point to be remembered when criticising a rope drive, is that in the case of a conversion, considerations of space, and non-interference with the work, may necessitate adopting this method of driving.

Mr. Kaula. Mr. R. J. KAULA: With regard to the author's remarks referring to 3-phase merchant mill drive, I am rather surprised that he has not made any reference to variable-speed or multi-speed 3-phase motors—I mean more especially a combination of cascade and pole-changing arrangements. The arrangement does away with the 3-pulley drive with equally good results, and at the same time eliminates the complication of rotary converters shown in Fig. 16. The author deals carefully with the power consumption of the various systems explained, but no reference is made to the power factor. Mr. Eckmann drew attention to this point, and I should like to mention that whilst the power factor has no appreciable bearing on the power consumption, it materially affects the capital cost of the installation. It would, no doubt, also have some effect on the terms obtainable from a supply authority, and where the installation under consideration includes the generating plant the power factor affects the cost of the generator to an appreciable extent, especially in the case of turbo-alternators.

Mr. Yerbury. Mr. H. E. YERBURY: I gather from the paper that the primary object of the author is to show what advantages accrue when a heavy flywheel is coupled to a motor for such work as rolling mills. That system will be readily appreciated by engineers, and there is no question that it is especially economical where power is taken from a supply authority on the maximum demand basis. The author is doubtless aware that he is now in a city where, I believe, all rolling is done by steam or gas-driven plant. I therefore regret to find that we have no data in this paper comparing the respective costs of each system, as we must admit that business and commercial men invariably sum up the problem from the £ s. d. standpoint only. I observe on page 622 that the author claims that one of the principle economies effected by electrical driving is that of the cost of power. I should be prepared to endorse that view, for many works where fuel is not an essential commodity, but for rolling mills we must admit that an exceedingly good proposition can be brought forward for a steam plant. I have in mind a case of a rolling mill where the waste gases from the furnaces are utilised for the generation of steam, and where the waste gases of a lower temperature are utilised for heating the feed water. I am not at liberty to give actual figures, but I can say that unless electricity could be purchased or generated at less than 0·5d. per unit it would not compare favourably with modern steam or gas-driven plant for all-round efficiency with a high load factor. There is not sufficient information in the paper to deal with the respective capital charges, but from the maintenance standpoint I should say that an electrical installation would be lower than steam plant. To my mind this is an instance where no hard and fast rule or line can be laid down, but each scheme should be considered on its own merits; but where coal can be purchased, as in

Sheffield, at 6s. to 7s. per ton, and gas at 11d. per 1,000 cub. ft., it will be readily seen that electricity has some formidable rivals. Mr. Yerbury.

Mr. W. E. BURNAND: Like Mr. Eckmann, I do not think the division suggested on page 595 is quite the best that can be adopted to indicate the group to which any particular system belongs. Continuous-slip regulators seem to cover pretty clearly the first, but for the other class I should prefer "auxiliary controlled," this latter covering two groups—one with a flywheel on the main motor shaft, and the other with a flywheel on the auxiliary machine. This division is probably capable of further improvement. The curve shown on page 609 looks to me hardly as a recording ammeter would show it. A certain amount of continuous slip action occurs which would round off the sharp angles shown. The value of the electric drive, at any rate in the large sizes, is to a great extent due to it being not only the most efficient, but the cheapest and most readily controlled gearing between the power generator and power-using machines. Take the case of the large 1,200-H.P. motor on page 604. To get this power to the mill would be an extremely awkward job for any mechanical engineer, and I do not see how it could be done to give the acceleration and reversing powers that have been pointed out. Most rolling mills have plenty of heat going to waste that can be used for steam generation on quite a large scale at a comparatively low cost, and I think the most advantageous way of utilising this steam would be by means of a steam turbine coupled to a generator, styled variously unipolar, homopolar, or acyclic. This is a hopeless machine for most present-day uses, but when we get up to 1,200 H.P. at turbine speeds for short-distance transmission I think it can easily hold the field to the exclusion of all others. 600 volts, for instance, could be obtained, say, with about four pairs of slip-rings, and whilst the design of the machine is a biggish problem to work out, it is feasible, which the ordinary commutator machine of this size for turbine speed most decidedly is not. With this combination of cheap steam and low cost of generating plant, I do not see how any outside supply can compete, especially as the load factor is far from good. Given a steam turbine as our prime mover, in view of the cheapness of steam in these places, I think the flywheel might with advantage be coupled to the turbine, and this latter allowed to vary in speed by the requisite amount to enable the flywheel energy to be utilised; and even though this reduces the efficiency of the turbine, it saves capital and complication and some conversion losses. I think it would pay to wind this flywheel with rectangular steel-wire like a gun, as with the higher peripheral speed that could then be utilised this would permit a much lighter wheel to do the work. I understand that the flywheels shown are steel [Mr. ABLETT: That is so], but I think that the saving in weight would pay for drawing down the steel into wire, and the labour of building up the wire-wheels. Mr. Burnand.

One more point I should like to suggest is that the series system is worthy of more attention than it has so far obtained for this class of work. For instance, with a series-wound generator and motor it

Mr. Burnand. is possible to obtain almost any desired performance as regards speed-variation between generator and motor with load without external appliances. For example, if both generator and motor have similar characteristic curves they will maintain substantially the same speed relationship with varying load, precisely as two shunt-wound machines do. If now the motor field is shunted by a non-inductive resistance the speed would at first increase with increased load, and then come down to its first value. If the motor field is worked nearer saturation than the generator, the motor would increase in speed with increase of load, with constant speed on the generator, or it could maintain a substantially constant speed, with a falling speed on the generator, enabling the flywheel energy to be utilised without additional apparatus. An additional flywheel machine can be utilised just as easily as with the parallel system, the extra machine armature being in parallel with the motor armature and the field in series. I do not wish to be understood as suggesting that these results cannot be obtained with the usual shunt or compound machines, but only that in many cases the series system is likely to be the most simple and least costly, with a reduction of excitation and auxiliary losses.

Mr. Walker. Mr. H. WALKER: I should like to know if the author can give us the units consumed per ton in connection with the 12-in. merchant mill, which he said were extremely low.

Mr. Ellison. Mr. N. ELLISON: On page 617 of the paper the author states: "The roughing rolls of a merchant mill should be run at the highest speed at which it is found practicable for the men to catch the comparatively short billet, and as in most cases about the same size of billet is being rolled, the speed should remain constant. The finishing rolls, on the contrary, should be capable of running at a large number of different speeds according to the shape and weight of section being rolled." In the case of a 12-in. mill I should like to ask the author whether he suggests that two motors are necessary to drive that mill.

DISCUSSION BEFORE THE NEWCASTLE LOCAL SECTION AT DARLINGTON ON 26TH FEBRUARY, 1912.

Mr. Stoney. Mr. G. STONEY: I was much interested in the diagrams showing the effects of various weights of flywheel; these seem to show that the choice of a flywheel is a matter of compromise. I notice that the slip regulator caused a loss of 15 per cent., which seems to be high, and I would like to have comparative figures for the Ilgner system, which, however, could not be much higher than 6 per cent. An important point seems to be the failure of automatic regulators, due to their time lag. It seems to me to be impossible to make an automatic regulator, which would act with sufficient rapidity to eliminate this drawback. It has been said that three or four mills working off the same supply would tend to equalise the load on the generating plant, but taking the analogous case of a tramway system, I know of instances where 50 or 90 tram-cars cause large variations in the load, and in one case where

Mr. Stoney.

10 tram-cars were employed the load varied from zero up to 200 per cent. above normal. Turning to Fig. 16, I think that the high-efficiency variable-speed set is most ingenious, and it might be worth while applying this system to an Ilgner set. With regard to the efficiency of rope drive, I am confident that the Lancashire mill owners would not have tolerated for so long a system in which the transmission losses amounted to even 10 per cent., and I think that 3 or 4 per cent. is a much more likely figure.

Dr. Thornton.

Dr. W. M. THORNTON: Some years ago I saw at the Gary Steel Works at Chicago a 10,000-k.w. rolling-mill motor giving every satisfaction. The losses in the rotor resistances of an induction motor are due to the desirability of adjusting its torque to be a maximum, by the cutting-in or -out of resistance to suit any particular load or slip. The mechanical power delivered to the motor shaft can always be expressed in electrical terms. For example, a power (W) at a current (i) is equivalent to a resistance (W/i^2), and where the power is mechanical it can be converted to electrical units. For each power there is a corresponding slip and by adjusting the ohmic resistance, and so the power factor in the rotor circuit, the maximum possible torque of the motor can be obtained from it at any load. By altering the resistance in this way the motor is partly relieved from the blow of the load. It provides a means of calling upon the supply mains for the extra energy wanted, without the motor speed falling greatly, and in this way the speed of the motor, as shown by the curves in the paper, could be kept much steadier. I think that the mass of the moving parts of the resistance should be as small as possible. The control shown in Fig. 11 is too feeble for the heavy plates. I suggest that if they have to be moved the control should be by strong solenoids actuated by relays. With regard to the great losses observed in the rotor resistances and ropes, I would like to know whether the power in the rotor circuit has been measured by a wattmeter. As regards the loss in the ropes I, personally, cannot believe that in a normal drive the losses exceed 2 to 3 per cent., and I feel sure that if the losses amounted to the figures given in the paper it would be impossible to keep the ropes from charring.

Mr. Marshall.

Mr. A. H. MARSHALL: Considering the action of the flywheel where the interval between passes is short, I might point out that to get the same work out of the flywheel it is necessary to use a larger motor. Regarding the terms "continuous-slip regulator" and "intermittent-slip regulator" I think it would be better to call these regulators the "fixed resistance type" and the "variable resistance type" respectively. Referring to the action of the intermittent-slip regulator as shown by Fig. 13, it is obvious that if this curve is a true representation of what happens there is no great gain in having a flywheel at all, as the motor, mains, and generating plant have to be large enough to handle the maximum load for an appreciable length of time. This might be true for a section mill, for there the load attains its full value at once, but for sheet mills I think the load does not rise so

Mr. Marshall.

quickly, and therefore this type of regulator could be used with advantage. I know of a case of a large mill where putting the automatic gear out of action makes a considerable difference in the load fluctuations. For continuous mills driven by 3-phase motors running at one speed there is probably nothing better, but at the same time some more efficient method of control, which would also improve the power factor, is badly needed. The regenerative arrangement shown in Fig. 16 is very suitable where more than one speed is required. I regret that the author has not extended the scope of the paper to give some everyday figures of the consumption in units per ton rolled and the comparative cost of driving direct by steam. Actually a comparison should be easy to make, as the tonnage gives something definite and tangible in the way of output on which to base costs. My experience is that actual costs are difficult to get hold of. In the Middlesbrough district there are seven large mills driven by motors of 1,000 H.P. or over and fed by 2,750-volt 40-cycle current: three on the Ilgner system; one of the type shown in Fig. 16; one a plain rotary converter job with a separate alternating-current motor for the roughing mills, and two with plain alternating-current motors and the intermittent type of regulator. These mills are working well, and in some cases doing much over their rated output. I know the history of all of them, and believe I am right in saying that there has been only one instance of trouble of an electrical character, and that has not been at all serious. The author is correct in pointing out the difference between operating from a large and from a small generating plant; by taking power from a large system the cost of the rolling-mill plant can be kept down and the speeds and output better maintained. This is because heavier momentary demands are permissible. It does not, however, lead to increased charges for power, as demands are usually taken on a half-hourly or hourly basis. In this respect the costs on page 612 are misleading; in no case, to my knowledge, are tariffs in this country based on maximum momentary demands.

Mr. Longman.

Mr. R. M. Longman: With reference to voltage variations caused by rolling mills, with a private generating plant, automatic regulation can be provided for the generators, but when the supply is taken from an outside source it is advisable to be able to steady the voltage at the works so as to have the least possible effect on the system. Is it not possible by some system of compensated or series motors, or by means of induction motors driven above synchronous speed, to provide the wattless current required and to keep the power factor at approximately unity and thus considerably to steady up the system voltage? In going round the works this afternoon I was struck by the enormous number of gear-wheels which are in use on machine tools, and I think that there surely must be some system of varying speed which would obviate the necessity for these. I agree with Mr. Marshall that in this country at least instantaneous peaks are not considered in any method of charging, and, as a matter of fact, I cannot understand how it was proposed to record these accurately. Was it proposed to take a

recording wattmeter chart, pick out the worst peak, and call that the maximum demand? Surely a quarter of an hour is the shortest period over which a peak load could be considered, and half an hour is more usual. The variation of the maximum demand when taken over a half-hour period and over a two-hour period is only about 8 per cent. If it was proposed to charge on instantaneous peaks, why not also charge on voltage regulation? Mr. Longman.

Mr. T. CARTER: I am glad that the paper draws attention to the large friction losses which might occur outside of the motor altogether, and I think that the present demand for extremely high efficiencies is absurd when 50 per cent. of the total input may easily be lost elsewhere. With regard to flywheel action, I remember a case in which this occurred in rather an uncommon way. A small motor-generator was installed on one side of a three-wire system, and after it had been at work for some little time the supply authorities complained that it was upsetting the voltage regulation, but a recording voltmeter showed that the pressure on the side on which the machine was working was actually steadier than it was on the other, and this could only be due to the flywheel action. Mr. Carter.

Mr. A. S. BLACKMAN: Speaking as a supply station engineer, I agree with Mr. Stoney that a large number of units of plant are required to straighten out the peak in a load curve. On a tramway system for which I used to be responsible, on which 200 cars were running, fluctuations up to 30 per cent. above the maximum occurred, and on another system, with 45 to 50 cars, the fluctuations were considerably greater. With regard to the maximum demand system, it is very usual now to take this on a one-hour basis, and this is the practice in Sunderland, although years ago the usual plan was to watch the instrument and take what was known as "snap" readings. Mr. Blackman.

Mr. JAS. INGHAM: As one who has been responsible for the design of a large number of modern sheet and tinplate rolling mill rope drives, I cannot agree with the author when he states on page 620 "that the use of a rope drive involves a loss of 10 per cent. of the power which the ropes are capable of transmitting normally." Exact information is difficult to obtain on efficiency tests of ropes. The only reliable test figures I know of were obtained on a specially designed rope drive in the laboratory at Charlottenburg. These tests show conclusively that with a well-designed drive a loss of only 2½ to 3 per cent. can be obtained. This figure is amply confirmed by experience of the rope drives in modern Lancashire cotton mills, and it is generally accepted that the loss in the ropes will not be more than 3 per cent. in a well-designed drive. The difficulty in designing rope drives for rolling mills is due to the large and sudden variations in power. Mr. Ablett, in a paper read by him before the Cleveland engineers,* in December last, gave a power curve showing the "actual power expressed in horse-power taken from the power house by a motor driving a sheet mill during 7½ minutes." No information is given as to the normal power of Mr. Ingham.

* *Proceedings of the Cleveland Institution of Engineers*, Part 2, Fig. 7, 1911–12.

Mr. Ingham. the motor, but it is probably a 600-H.P. machine. An examination of this curve shows that maximum peaks of 800 H.P. may be expected, and that the average load will be about 320-H.P. The problem then for the designer is to design the rope drive so that an *average* load of 320 H.P. can be transmitted from a motor or engine of 600 normal horse-power, which can deal with peak loads of 800 H.P. without unduly straining the ropes, and at the same time will give the highest possible efficiency on the whole range of load. This problem includes the question of the variation of efficiency with load. I agree with the author that whatever the amount of the loss in horse-power may be at the designed load, this loss will be fairly constant in amount over the whole range of load. On examining the following table, it will be seen that the

	Horse-power.	Friction Loss in Horse-power.	Friction Loss, Per Cent.
50 per cent. overload ...	900	17	2
Normal load	600	17	2·8
Rope design load	500	17	3½
Average load	320	17	5·3
50 per cent. normal load ...	300	17	5·8
25 per cent. normal load ...	150	17	11·3

constant horse-power loss means a seriously increasing percentage loss as the load is reduced. It must be obvious, therefore, that to get the best efficiency the number of ropes should be so arranged that for the maximum time they are running with the full load, or as near full load as possible. It would appear, therefore, that from the point of view of efficiency only, the ropes should be designed for the average load. Against this, however, we must remember that some margin is necessary for dealing with the peak loads, so as not to overstrain the ropes. The fixing of the correct number of ropes, therefore, becomes largely a matter of experience in this particular class of work. A large number of rope drives have been designed to deal only with the peak loads, and will, therefore, be responsible for a loss of 10 per cent. or more on the average load. There can be no doubt, however, that such drives are over-roped, and more than one case is known where from one-quarter to one-third of the ropes have been taken off with resulting higher overall efficiency. When I can have a free hand I have fixed the rope design load at from 80 to 90 per cent. the normal power of the motor. In the case given above this power would be about 500 H.P. Using 42 H.P. per rope for a 2-in. rope at 3,200 ft. per minute, I should put in 12 ropes for this drive. It will be found that

many drives under the above conditions have 16 to 20 ropes. Designed on these lines, and with first-class ropes, I would guarantee the loss in the ropes at a load of 500 H.P. to be not more than $3\frac{1}{4}$ per cent.; at the average load of 320 H.P., 5·3 per cent.; and the life of the ropes two years, working 120 hours per week. I admit the life of the ropes will be shorter than if, say, 16 ropes were put on, but the cost of new ropes is relatively a small matter, as shown by the following. If the above drive is 60 ft. centres, the ropes will cost about £10 per rope. The average life of a rope driving tinplate mills is about three years, so that the cost per year of ropes $= 10 \times 16/3 =$ £$53\frac{1}{3}$ every year, replaced every three years. Now the cost per year of twelve new ropes $= 12 \times 10/2 =$ £60 per year, replaced every two years. So that the difference in the cost of ropes is only £7 per year. Assuming, however, that the efficiency of the plant is increased a 3 per cent. saving in power $= 3 \times 320/100 = 9{\cdot}6$ H.P. At 0·3d. per horse-power this equals, for 120 hours per week, £75 per year. I maintain, therefore, that instead of obtaining a loss of 10 per cent. at the normal power, as the author states, it is possible so to design a rope drive that only 5 per cent. loss will take place at the average power, which equals, as the above table shows, 2·8 per cent. of normal power, or only one-quarter of the author's figures. Mr. Ingham.

Discussion before the Birmingham Local Section, 27th March, 1912.

Mr. W. W. Wood: The question of the friction of flywheels is a very important point, and one about which very little is known; it would therefore be of interest if the author could give some particulars as to what power is required to run flywheels of different sizes. On page 600 the author deduced that a larger constantly rated motor was required with a light than with a heavy flywheel, but the difference in power was apparently very slight, and would be, surely, more than offset by the extra power required to drive the heavy flywheel. The earliest form of slip regulator in a rolling mill might be described as an intermittent-slip regulator hand-operated. It consisted of a liquid starter arranged with a lever so that the plates could be easily withdrawn, and was worked by a boy. The arrangement sounded, perhaps, rather crude, but was very effective, and with a little practice it was very easy to keep the load on the motor practically constant. The advantage of using a boy to operate the regulator instead of a motor was that the boy could anticipate the demand and move the regulator before the load actually came on. The author had compared the relative advantages of a direct and rope drive for a non-reversing mill very much to the detriment of the rope drive, but in doing so he had assumed that the loss in the driving ropes was 10 per cent. of the normal power they were capable of transmitting. I believe that in the past it has been a very common thing to assume the loss in the rope drive as 10 per cent., mainly because no one knew exactly what it was, Mr. Wood.

Mr. Wood. but in a recent paper * Mr. E. Kenyon referred to tests which show the loss in rope drive as only $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent. I have had a great deal to do with rope drive for electrical purposes, and with a properly designed arrangement I can quite believe that the loss is not more than Mr. Kenyon has stated. It seems to me, therefore, that it would be nearer the truth to state that the loss in a properly designed drive would just about off-set the lower efficiency which the slow-speed motor had, and there would not therefore be the great saving in the units used to which the author has referred. In comparing the two methods of drive there are a number of points which must be taken into consideration. The driving ropes form an excellent coupling between motor and mill, far more flexible than we could hope to obtain in a direct drive, and relieve the motor of shock very considerably. It is also possible that we might have a case where 3-phase current is already installed; and to drive a mill running at perhaps 40 revs. per minute would require a freak design of motor, particularly if it had only to develop 450 H.P. If in this case it were decided to drive with a continuous-current motor, the machine would, of course, be more reasonable, but the heavy loss from converting from 3-phase to direct-current would have to be faced, and this would give a result in units used very much in favour of the rope drive. Before it can be stated that either rope or direct drive is the better, the circumstance of each case should, I think, be carefully considered.

Mr. Rosher. Mr. N. B. ROSHER: Although it is essential that the principles and method of operation of flywheels should be understood, yet the theoretical curves show the variation of motor-power and speed with different flywheels, and different conditions of passes which appeared in Figs. 4 and 7 do not all represent the conditions which were usually met with in mills in the Birmingham district, especially in sheet mills where a number of rolls are driven from one train and the peaks which occur are very irregular. No mention is made in the paper of the connection of the motor to the mill. This matter is, I consider, of considerable importance, as unless the connection of the motor to the mill is well thought out, trouble is likely to ensue. In my opinion, to gear the motor to the roll train without inserting some flexible form of coupling is not desirable, because shock and vibration are transmitted to the motor. The continuous-slip regulator is a very desirable adjunct to the electrical equipment of a rolling mill. I am connected with a sheet mill where a 250-H.P. motor drives through spur-gearing on to a big roll train without any flexible coupling; there was a considerable grind from this drive until a permanent resistance giving 10 per cent. slip from no load to full load was inserted in the rotor circuit. In describing the possible ways of effecting change in speed of a 3-phase motor drive, the author made no mention of pole-changing devices or of Cascade motors. With regard to economies effected by electrical driving, I think it would be interesting if I gave some figures with respect to a sheet rolling mill with two main roll trains, the larger electri-

* *Proceedings of the South Wales Institute of Engineers*, vol. 26, p. 252, 1908.

cally and the smaller (which had two main roll trains, the larger of which was converted from steam to electricity some four years ago) being still steam-driven. The conditions under which both trains operated were very similar, but in the case of the steam-driven train the costs per B.H.P. per annum were about £11, whereas the cost of the electric drive per B.H.P. per annum was only £4. The steam engine is shortly to be replaced by an electric motor, and it is estimated that the electric drive will pay for itself in a little over two years. Mr. Rosher.

Dr. S. P. SMITH: There is one matter in the author's paper on which I should like information. Referring to the scheme in Fig. 16, which the author said had been installed in three mills in this country, it would be interesting to know if the arrangement shown, which might be described as giving constant output at all speeds for a given input, is better for the kind of work in question than the arrangement with the auxiliary machines mechanically independent of the main motor, which is suitable for giving a constant torque at different speeds. Both systems have been developed of late years, and the 3-phase commutator motor and the induction generator have both found useful applications thereby. There is a further arrangement about which I am sure the author could give some useful information. This is the frequency changer developed by the Siemens-Schukert Werke in conjunction with Heyland. This interesting machine is made to convert from the frequency of the supply to that of the rotor currents of the main motor at the speed required. The armature is very similar to the armature of a rotary converter, whilst the stator completes the path for the flux. Could the author say what success has attended the application of this ingenious arrangement which permits of the working of the main motor both above and below synchronism? Mr. Smith.

Mr. JUDGE: I am in favour of the rope drive as being a very good flexible coupling. Mr. Judge.

Mr. MORE: I have had experience of electrical driving for rolling mills, and think very favourably of it. Mr. More.

Mr. W. E. MILNE: Rolling mill owners appear to pay too little attention to the question of mechanical arrangements when electrifying a mill. The only thing which appears to be of any importance to them is the price of current. This outweighs all other considerations, and owners who are waiting for a low cost per unit could easily effect startling economies by calling in a competent mechanical engineer to overhaul the driving arrangements. A test taken by the Birmingham Corporation Supply department in a metal works some time ago showed a transmission loss of 70 per cent., while losses at 40 or 50 per cent. are not uncommon. I quite agree with the author that friction losses, which are constant, should be kept as low as possible. There is a tendency in Birmingham to put too many rolls on one motor; the long, heavy train of gearings for such arrangements call for a considerable amount of power to drive them. Referring to the use of slip-ring regulators in brass and copper mills, the automatic slip regulator is not required in these mills, although the introduction of a Mr. Milne.

Mr. Milne. small amount of permanent slip might be an advantage in certain installations. Dealing with the question of flywheels, I am of the opinion that this question has received too little consideration. The majority of Birmingham mills have changed over from steam driving and a badly balanced steam engine flywheel is usually left in. The size and position of the flywheel should receive more consideration, and, speaking generally, if the motor is not driving too many pairs of rolls the motor might be smaller, and the flywheel larger, than usually found.

Mr. du Pasquier. Mr. A. du Pasquier: I had an opportunity of taking part in the Sheffield discussion, and ventured to suggest that the author's calculations on page 620 of the paper were incorrect, as he did not appear to have debited the slow-speed motor with any slip loss. It is not an easy task to criticise the author's paper. I think every electrical engineer interested in that particular class of work must appreciate the excellent work the author was doing for the industry generally by his consistent, energetic, and very able advocacy of the electric drive for rolling mills. It occurs to me, however, that these slip losses had been taken account of in the 15,300 units per week mentioned. So the only point between myself and the author is, whether the figure given in the paper for rope loss is not unduly high, and whether it is fair to take this 10 per cent. loss on the gross figure including 5 per cent. slip loss. I agree that the slow-speed motor can always justify the additional outlay where rope driving is the alternative. Gear-driving is another matter: it is no doubt more efficient, and gets over the power factor difficulty, which in the case of a sheet mill and a 50-cycle supply system might be a considerable one. I should like to point out, however, that sometimes either from questions of loss of output during conversion, or space restriction, a rope drive might be the only solution. The author mentioned the case of a 600-H.P. motor driving a sheet mill by means of twenty 2-in. ropes. This is certainly an excessive number of ropes to transmit the ordinary overloads of the motor, and presumably the flywheel in this case must have been on the motor shaft and discharging through the ropes: this is an undesirable arrangement. In view of the author's alarming estimate of rope losses, it is interesting to note that recently he has recommended a rope drive for a new sheet mill on the north-east coast. The 3-speed rope-pulley drive has, I consider, been rather hardly dealt with. After all, the commercial solution of an engineering problem is nearly always of the nature of a compromise. It is not always that we are able to put down what is absolutely the best from a technical point of view, other conditions unfortunately creeping in, and there is no doubt that the 3-speed device, while costing much less than any other system of economic uniform speed control, is giving complete satisfaction in practice. I must take exception to the comparison which the author made between the very ingenious but somewhat complicated system illustrated on page 619 and the simpler arrangement of standard rotary converter and direct-current mill motor which serves the same purpose. As regards efficiency, when applied

to one mill only there is little or nothing to choose between the two systems, but from the points of view of simplicity and first cost the advantage should be with the rotary converter system, these advantages being intensified when more than one mill is to be operated, as would usually be the case. The additional transformer if required is a particularly reliable piece of apparatus. It is highly efficient, and at very little additional cost it could be designed to stand any distortion due to stresses that might be occasioned in the somewhat unlikely event of a short circuit on the secondary side. The rotary converter, owing to the much smaller armature reaction and field distortion, is admirably suited to deal with the momentary heavy demands which this class of work entails. The author has given a good idea of the extent of the variations in power demand with more than one mill. At the time of the Sheffield reading such variable-speed devices were suggested in relation to the driving of merchant mills where a considerable range of speed is necessary. I have reason to believe that the author is not advocating this system for the driving of sheet mills where an average slip is of the nature of 5 to $7\frac{1}{2}$ per cent. as a maximum; the idea being to save as far as possible the rheostatic losses and possibly to diminish the demand upon the system by something short of this amount. In slips of this magnitude, however, I have no hesitation in saying that variable-speed devices with their considerably increased first cost, greater complication, and greater space occupied, are commercially unsound and their advocacy is to be deprecated. I believe that the general opinion on the Continent, where the system had its origin, would support my views. Mr. du Pasquier.

Mr. A. M. TAYLOR: I should like to point out that the proportion that the fixed charges bear to the total cost per unit is reduced as the total load on the power station increases, and also as the load factor improves through the increase of the power demands. It is therefore to the interest of manufacturers to come on to the corporation mains. With regard to the overload capacity of electrical machines, we are on the eve of important developments. Much greater loads than 100 per cent. are quite practicable. At the present time a booster set is being supplied to the corporation which would be capable of carrying an overload of 500 per cent. for 10 seconds. Mr. Taylor.

Mr. R. ORSETTICH: I should like to ask how the diagrams showing the variation of the power and speed of a rolling mill motor under practical conditions were obtained. Compound-wound direct-current motors are very suitable for driving rolling mills. A 300-H.P. machine recently supplied for this purpose by my firm is heavily compounded, and gives 28 per cent. from no load to full load. I do not agree with the author that the Ilgner system involves a total increase in the capital cost of only 10 per cent. I have been closely into this matter in connection with a 10,000-H.P. plant, and find that the increase is from 20 to 25 per cent. As regards the rope drive, there is room for discussion. The 10 per cent. loss in ropes given by the author is probably correct. Mr. Orsettich.

Mr. Orsettich. In my opinion, the best drive is the direct one without flexible coupling, the next best the rope drive with the flywheel on the roll shaft, and the last the rope drive with the flywheel on the motor shaft.

Mr. Moffett. Mr. F. J. MOFFETT (*communicated*): In his paper the author mentions two devices for producing a fall in speed of the motor when the load increases, viz., the continuous- and the intermittent-slip regulator. The first involves a continuous loss of power, even at light load, and the second is so sluggish in action that it allows a serious overload to come on the motor before any considerable drop in speed takes place. A mechanical-slip regulator appears to be superior to the two methods mentioned. If a suitable slipping clutch is inserted between the motor and the mill, it is possible in case of emergency to produce a slip of 100 per cent., and then utilise the whole stored-up energy in the flywheel. This is the only particular in which the steam engine drive possesses any advantage over the electric motor drive. At times of excessive load a steam engine will almost pull up; but when the overload on the electric motor has reached the limit of safety the automatic cut-out comes into action, and the power is entirely cut off. Slipping clutches suitable for this purpose are made by several firms. One type, of which I have had satisfactory experience, works on the centrifugal principle, the power being transmitted by means of the radial pressure of slipper blocks against the inside of the rim of a hollow pulley, the slipper blocks driving on one shaft and the pulley on the other. Another well-known type of clutch is the Hele-Shaw. With either of these clutches it is possible for slipping to take place at a different point, so that the losses at light load are negligible, and there is practically no time lag in their action. Ample protection can be afforded to the motor, since provision can be made that the load shall not be more than it can carry with safety. The speed of the rolls can fall until they come to rest, but the motor is still able to exert its maximum torque. I am not aware that clutches of this description have been applied to rolling mill drives, and I shall be glad to have the author's views on this proposal. The clutch would, of course, need to be of sufficient size to dissipate the heat generated by friction. Additional advantages due to the adoption of this type of slip regulator would be, firstly, that in the case of a 3-phase motor a short-circuited rotor could be used instead of the more expensive and less efficient wound rotor, since the motor would start under practically no load; and, secondly, that there would be no need for a flexible couple, as the clutch would serve this purpose admirably.

Mr. Ablett. Mr. C. ANTONY ABLETT (*in reply*): I regret that on page 620 of the paper the question of the losses in a rope drive was not sufficiently clearly stated, and it should have been said that in every case of an electrically driven sheet mill that I have had the opportunity of investigating, sufficient ropes have been installed to transmit normally about double the normal motor power without overloading the ropes. It is not unreasonable to consider the rope losses as

Mr. Ablett.

consuming 5 per cent. of the normal power which the ropes will transmit, and this loss goes on whether the ropes are transmitting their full power or not. So by adopting a rope drive of a sheet mill we have a continuous loss going on, due to the rope drive, which amounts to about 10 per cent. of the normal motor power. This loss is more important in the case of a sheet mill than in any other type of mill, because the average power required by the sheet mill is small compared with the maximum power. In fact, the average power required for a sheet mill is often not more than ⅓ of the normal motor power, so that in an unfavourable case the ropes can consume as much as ⅓ of the total number of units of electricity which are taken by the rolling-mill motor. Values for the losses in rope drives have frequently been mentioned which are less than 5 per cent. of the normal powers which the ropes can transmit, but it is found that the losses have frequently been ascertained by testing steam engines which are transmitting power through ropes, and an estimate is made of the total power transmitted; the friction of the engine is also estimated, and the difference ascribed to the rope drive. This cannot be regarded as an accurate method, as the unavoidable error in indicating the engine is more than the percentage loss attributed to the ropes. I am of opinion that the only accurate way of determining the rope losses is to drive a dynamo from an electric motor through ropes under such conditions that the rope losses form a fair proportion of the powers of these machines. The input to the dynamo and the output from the motor can be measured accurately, and the efficiencies of the machines can also be determined accurately, so this gives an accurate method of determining rope losses. It is to be hoped that some data obtained in this way may become available in order to throw definite light on this important question.

Several speakers have referred to the economies to be obtained by electric driving, this being a question, however, which was not entered into in the paper. It is interesting to note, however, that there are more than 100 electrically driven rolling mills in this country, and more than 1,000 electrically driven mills on the Continent. There are over 50 electrically driven reversing mill installations in Europe, of which about 30 are at work, the remainder being in course of construction. These figures alone are sufficient to show that electrical driving has justified itself, and that there are many cases where the adoption of electric driving for rolling mills will pay very well.

Several speakers have referred to the question of shocks on the rolling mill motor, and mention flexible couplings and rope drives as a means of taking up these shocks; in this connection it must be remembered that at the present time in Europe there are 30 electrically driven reversing rolling mills at work, in almost every one of which the motor is direct coupled to the pinions of the mill, and in one or two cases even it is direct coupled to the rolls themselves, the pinions being on the far side of the mill, and no flexible coupling of any form being used. These mills are doing the heaviest work, and are driven by

Mr. Ablett. motors capable of giving as a maximum as much as 20,000 H.P., so that it would be difficult to find a case where shocks are more likely to make themselves felt than in an electrically driven reversing rolling mill. Some of these reversing mill motors have been at work for 4 or 5 years, and not the slightest difficulty has been experienced from shocks. In view of this, it cannot be said, in the case of small mills driven by motors up to 1,000 H.P., or over, that the effects of shock are in any way to be feared. A flexible coupling, however, has its uses in the case of a mill motor driving a rolling mill where a flywheel is employed, and this flywheel is carried in separate bearings, a flexible coupling interposed between the motor and the flywheel will protect the motor bearings from any ill-effect due to possible slight lack of alignment between the motor shaft and the flywheel shaft. This, of course, refers to such a case where the motor is carried on its own bed-plate and where the flywheel bearings are supported by separate sole-plates.

The application of an exciter to a motor-generator set which Dr. Rosenberg described is very interesting, because it goes part of the way towards obtaining what we should all like to have for rolling-mill work—that is to say, a compound-wound motor in which the compounding only becomes effective after the load attains a certain value.

Regarding the application of high-tension current to the motor of the variable-speed set, I have seen many mill motors running on a 5,000-volt supply, and several on a 10,000-volt supply, and I feel assured that in the present state of electrical knowledge few manufacturing firms would have the slightest hesitation about the direct application of high tension to a 3-phase motor. The question of the possibility of the heating-up of the rotary converter when the variable speed set is running at its top speed has been raised, but this has not occurred in any of the numerous variable speed 3-phase sets which are at work.

Dr. Wiesengrund remarks that the maximum overall economy of a plant would be reached when the combined total capital charges and the running charges become a minimum, and while this is quite a correct principle, yet undue weight should not be given to the capital charges, as the running charges as a rule are more important. As an example, in the case of an electrically driven reversing rolling mill recently, the cost of power for rolling a ton of steel would be either 6d. or 9d., depending on the weight per foot of the section rolled, while the capital charges per ton of steel would only be 0·15d. for each £1,000 of capital expended. I must say that I do not like the idea which has been suggested of transmitting the power of a flywheel through gearing, because the power which the flywheel gives up is determined entirely on the rate of deceleration of the wheel and so is quite indeterminate if the maximum power required by the mill is not known, as would be the case if a collar occurred. In dealing with the case where such indeterminate powers may have to be transmitted, it would appear desirable to interpose as little transmission gearing as possible between the flywheel and the mill—that is to say, the flywheel should run at the

Mr. Ablett.

same speed as the mill and be coupled either to the mill or the pinions through the ordinary arrangement of spindles, which break if subjected to excessive strains and can easily be replaced. The breaking of gearing in such a case would be a far more serious matter. It would have been very valuable if Dr. Wiesengrund had stated where the arrangement of the flywheel on the high-speed shaft, as proposed by him, is in operation, and what the experience with it has been ; also it would be interesting if he had quoted figures to show how the high-gearing efficiency which he mentions is maintained throughout the life of the gears.

Mr. Howard has given a very interesting comparison of the Welsh and American systems of rolling tinplates, which shows how the large outputs are obtained in American tinplate mills without exceeding the physical endurance of the men. Where such large outputs are obtained, the cost of production is naturally much cheapened, partly because the capital charges per box of tinplates produced is reduced, but principally because the kilowatt-hours taken to roll a box of tinplates is reduced, since the constant friction load of the tinplate mills has to be divided up among a much greater number of boxes of tinplates produced.

Mr. Matthews has mentioned that American practice in rolling mill work seems to favour the use of induction motors, but it should be pointed out that in Continental practice about as many direct-current motors are used for driving rolling mills as induction motors. Some of the first mills to be driven electrically were driven by direct-current motors, which have been at work for fourteen years or so ; these have quite justified themselves from the point of view of reliability, and it should always be remembered that in rolling-mill work the direct-current motor proves more reliable and offers great advantages from the point of view of easy speed-control. In the case of a works having its own power station, it does not seem that the question of power factor is very important, compared with the case where power is taken from a supply system, particularly where the same supply system is also supplying a large lighting load, and it would seem that the conditions must be very exceptional where the installation of a 5,000-k.v.a. rotary condenser is justifiable in order to improve the power factor.

Mr. Fasola has drawn attention to the fact that in Figs. 4, 5, 6, and 7 no allowance has been made for the extra power consumed by the slip resistance, should these represent diagrams for a 3-phase rolling-mill motor.

The curves on these diagrams were drawn to show the variation in motor output so as to be applicable to direct-current or 3-phase. Naturally, if a 3-phase motor should be employed to drive the mill and the motor input has to be considered, allowance must be made for these slip losses which will increase the peaks shown in these curves and will materially increase the variations of power given in the table on page 599.

With regard to the adoption of a motor having a direct-coupled

Mr. Ablett. flywheel which would be arranged to run at $\frac{2}{3}$ speed during the first passes, and then speeded up to top speed during the last passes, it is to be feared that this would cause some delay, especially if the flywheel were a heavy one, because the time taken to speed up would be appreciable on account of the amount of stored energy to be given to the flywheel, and also when the bar was finished and it was desired to enter a new billet into the roughing rolls, either it would be necessary to wait until the mill slowed up of itself, which would easily take several minutes, or else a brake would have to be applied to the flywheel. In any case there would be a loss of power unless the mill motor were a direct-current motor. The difficulty about using motors running at three fixed speeds for driving merchant mills is that three fixed speeds are not sufficient for the mill, and a large number of other speeds are required. This means that where a 3-phase motor is adopted, which is arranged to run at three fixed speeds, it is usually found to be running in practice with slip resistance in the rotor circuit, in order to obtain the exact speed required, and this involves waste of power.

Mr. Allingham has referred to the use of the flywheel as a means of equalising the power demanded of a rolling mill, and has suggested as an alternative the use of a storage battery, but for reasons detailed below I cannot see any wide field for the storage battery in steel works. In considering this question, attention has to be paid to two distinct cases. First, that of a reversing rolling mill or of a 3-high mill driven, on the Ilgner system, where the rolling mill motor is supplied from a motor-generator set on the so-called Ward-Leonard system, this motor generator set being provided with a flywheel. The primary object of adopting this motor-generator set is to obtain a very rapid and easy speed control, so that a large output can be obtained from the mill. The addition of the flywheel to equalise the power demanded is a secondary consideration. Secondly, the case of an ordinary two- or three-high mill driven by a continuous-running motor, to which a flywheel is coupled. In both these cases, if the flywheel were dispensed with and a storage battery used to obtain power equalisation, the motor driving the motor-generator set in the first case, or the rolling mill motor in the second case, would have to be made large enough to cope with the maximum power demanded by the mill, and in practice it would be found necessary to adopt motors of four or five times the size that is necessary where a flywheel is used. The extra cost of these large motors would be considerably more than the costs saved by dispensing with a flywheel, and in addition to this the cost of a storage battery would be incurred, so that the storage battery arrangement would prove more costly than the flywheels which are usually used, and there is no apparent advantage to be gained in incurring this increased cost. Where there are a number of rolling mills in one works, the fluctuations of power of each mill motor tend to balance one another, thus rendering the demand on the power supply more or less steady, as illustrated by Fig. 14; so that in such a case it is extremely doubtful whether the provision of an equalising device is justified. It could hardly

be assumed that the rolling mills in a works are working more or less irregularly, because such a method of working would mean that the output would be small and the cost of production heavy. It is the mill manager's constant aim to get as large an output as is possible out of a given mill, as this naturally lowers the cost of production, and to do this the mill must be kept regularly going all the time, the variations in power being such as occur between the pass and the interval between passes, which are kept within reasonable limits by the flywheel. Naturally many rolling mills, particularly merchant mills, have to stop at times for changing rolls, but it is also the aim of the manager to change rolls as seldom as possible. The time occupied in rolling should be long in proportion to the time occupied in roll changing, so there is not much advantage to be gained by storing energy in a battery during the period of roll changing in order to give it out again during the period of rolling. Mr. Ablett.

It should be pointed out that the losses of a flywheel are constant, independently of the power which it takes in and gives out, so that the harder the mill is working the more efficient the flywheel becomes as a power equaliser, and at the full output of the mill the flywheel losses can easily be only 1 or 2 per cent. of the total number of units of electricity taken to roll. On the other hand, the losses of a storage battery are proportional to the power which it stores and gives up again, so that these losses increase as the mill is being worked faster, probably in such a manner that they amount to a fixed percentage of the total number of units of electricity taken to roll, and it would be of technical interest to see whether this percentage could be reduced below, say, 10 per cent.

Dealing with the case of a storage battery applied to a 3-phase system from which rolling mills are supplied, I am of opinion that if such a case should be fully investigated it would be found both cheaper in capital cost and more efficient in operation to convert the whole of the current to direct current and to apply direct-current motors to the mills, the storage battery being employed on the direct-current side of the system, because of the large proportion which the maximum powers bear to the average power which the rolling mill motor would take in such cases, if it were not provided with a flywheel. Thus the average power would be converted from 3-phase to direct current and the maximum powers would not have to be converted from 3-phase to direct current, and *vice versâ*. I am only aware of one case where a storage battery is used in steel works, and this is where an electrically driven blower is used for blowing the Bessemer converters and the electric power is transmitted from a gas-engine-driven power house some 5 miles distant. A storage battery is provided of such capacity that if the electrical supply should fail the blow of the converter could be finished from energy supplied by the battery, and the ingots cast, thus avoiding the possibility of spoiling the steel in the converters, or damaging the converters themselves. These works possess a large number of electrically driven rolling mills, and in every case flywheels are used to keep the fluctuations in power within reasonable limits.

Mr. Ablett. Mr. Alan Williams has referred to slip resistances and series resistances in connection with rolling mill motors, and has described a direct-current system in this connection. The usual practice is that where a direct-current rolling mill motor is used it would be a compound-wound machine, so that the speed falls as the load increases, enabling the flywheel to give up its stored energy in order to assist the motor where the demand for power is great. Such a compound-wound motor falls in speed without involving any loss of power, and no series resistances, which would cause a loss of power, are required. Further, to suit the rolling of different sections in a merchant mill where the mill is required to run at different speeds, according to the section being rolled, the speed of the mill motor is varied by shunt regulation, and in practice it is found that the variation of speed required for the mill is always less than the variation which can be obtained by shunt regulation. Where the speed is varied in this manner by shunt regulation, the turning moment increases as the speed falls, which is very suitable to the requirements of the mill, as heavy sections requiring larger turning moments are usually rolled at the lower speeds.

The C.M.B. system, which has been described above, offers an alternative method to the employment of a compound-wound motor where speed variation is obtained by shunt field regulation, and the adoption of this system would enable a rolling mill motor of a smaller and cheaper type to be used, but against this it must be remembered that this advantage is obtained by installing an additional machine, namely the direct-current dynamo which is coupled to the rotary converter, and the capital cost of this additional machine is to be considered, so that on the whole the capital cost of the plant will probably be increased. Further, this C.M.B. system would not be so economical as a plain compound-wound motor, as the electrical losses of this additional dynamo have to be considered. The C.M.B. system as far as rolling mill work is concerned, involves additional complications, and it is not evident that it offers any corresponding advantage so that it seems hardly likely that it will find a field of application for rolling mill work.

Mr. Mountain has raised the question of the comparison of the cost of rolling per ton between electrically driven rolling mills and those driven by high-class economical steam engines in conjunction with exhaust steam turbines, and presumably he refers to reversing rolling mills. It is not possible to make a general statement about this, because the comparison depends to a great extent on the conditions obtaining in the works using the reversing rolling mills, and it is seldom possible to name two works where the conditions are the same; but if a number of cases be investigated at random it will be found that a large proportion show results favourable to electric driving. One of the most obvious cases which is favourable to electric driving is that of a steel works having blast furnaces producing a definite amount of gas. If this gas is utilised in the most economical manner, that is to say, if gas engines are installed to blow the furnaces and to produce

Mr. Ablett.

electric power, a part of which will be used to drive the reversing rolling mills electrically, the gas in most cases will suffice to produce all the power required for the works. If, on the other hand, steam reversing rolling mill engines, together with exhaust steam turbines are used, and that gas which remains over after a sufficient quantity has been taken to heat the stoves and to supply the blast for the furnaces be burnt under boilers to raise steam, it is found in general that there is not nearly sufficient gas to produce the power required, and that considerable quantities of coal have to be burnt, the cost of which can easily run into many thousands of pounds per annum, even to tens of thousands. It should always be remembered that the amount of gas available, which may be looked upon as one of the natural resources of an iron works, is strictly limited, and so this limited amount of gas should be made use of to the best advantage. I have in mind a case of some high-class economical rolling mill engines, less than four years old, rolling rails in a works where the conditions are generally as above and where coal has to be burnt to supply the surplus quantity of steam required for the engines, which cannot be raised by burning gas. The cost of power is said to be of the order of 2s. 6d. per ton. If gas engines are used and the electric drive installed for driving the reversing rolling mills, then Continental practice has shown that power can be generated for less than 0·15d. per unit, including all capital and upkeep charges. This would enable rails to be rolled for a power cost of 6d. per ton, against 2s. 6d. for steam.

It is doubtful whether the enormous progress which the blast furnace gas engine and the electrically driven reversing rolling mill have made on the Continent during the last four years is fully realised in this country. Any engineer who chooses to make an investigation of the working of large blast furnace gas engines on the Continent will find ample proof that they are showing themselves as reliable as slow-speed steam engines, and it is sufficient to say that there are over 50 electrically driven reversing rolling mill plants on order or at work on the Continent, and the managers of the various works have decided to adopt the electrically driven reversing rolling mill, after the leading manufacturers of high-class reversing rolling mill steam engines have had every opportunity of showing what they can do with their most improved type of modern engine. It is well worth the while of any engineer who is concerned in these matters to investigate the conditions in the Continental steel works at the present time, and there is little doubt that he will find the results surprising.

The advocates of the exhaust steam turbine for use in conjunction with rolling mill engines are wont to overlook a number of important points. One of these points is that an efficient combined plant, namely, a reversing rolling-mill engine and exhaust steam turbine, cannot be made unless the steam engine itself is a very efficient high-class machine. A little consideration will show that this is the case. The effect of moisture in the low-pressure steam in the steam consumption of the exhaust steam turbine is sometimes lost sight of altogether. The effect

Mr. Ablett. of the exhaust steam turbine in diminishing the output, which can be obtained from the mill, and in increasing the steam consumption of the reversing rolling mill engine, has not been sufficiently considered; the former is a most important point on account of the effect it has on the cost of production per ton of steel, while the latter point has been dealt with in a paper by Mr. T. B. Mackenzie,* entitled, "On Means for Economising Fuel and Utilising Waste Heat in Malleable Iron and Steel Works."

Mr. Norman Hockley has called attention to the speed curves of the motor, for which Fig. 12 in the paper was drawn. In drawing these curves, it was supposed that the motor was a shunt-wound machine, having a practically constant speed characteristic—a condition which can be obtained with a suitable armature reaction—and this case was chosen in order to keep the issue clearer. Mr. Hockley's suggestion of the combination of a continuous- and intermittent-slip regulator, consisting of a compound winding and an automatic apparatus for strengthening the shunt field, is an ideal one to meet certain cases, and this finds application in the case of the motor driving the flywheel motor-generator set supplying an electrically driven reversing rolling mill.

Mr. Eckmann has referred to my suggestion that the two forms of slip regulator should be renamed because the present custom of naming one of these slip regulators "automatic," when both are automatic in their action, is misleading. While I think there is still room for improvement in the names which I suggest, I also think that the names suggested by Mr. Eckmann do not meet the case because he still introduces the word "automatic" into the name of one regulator and not into the other. With reference to the question as to whether the regulators should be called slip regulators or current regulators, I think this depends largely on the point of view from which the question is regarded. From the mechanical point of view there are advantages in the term "slip regulator," as it conveys at once the fact that the flywheel falls in speed, giving up its stored energy. Mr. Eckmann also criticises my statement that there is no cause for alarm about the flywheel not regaining its stored energy where long passes are succeeded by short intervals. Naturally, as was pointed out in the paper, in such a case the average power will approach nearly to the maximum power, so that the flywheel is not of very much benefit, but in such a case the flywheel will regain its speed and there will be no difficulties caused by the mill running continually below speed. At the same time, I am obliged to Mr. Eckmann for pointing out that the power taken during the passes in curves 4, 5, 6, and 7 should not be shown as constant, but as diminishing as the speed decreases. If the curves are shown in this way, the maximum power required by the motor is reduced, and a slightly greater accuracy is obtained from a theoretical point of view. This, however, would involve considerable complications in the calculations, which, after all, are based on certain

* *Transactions of the Institution of Engineers and Shipbuilders in Scotland*, vol. 54, p. 289, 1910-11.

assumptions that may give rise to certain errors. The method which I show in the paper tends to make the motor too big rather than too small, which from a practical point of view is not a bad fault in rolling-mill work, where the power required to roll the material on which such deductions are based cannot be determined with scientific accuracy, but is subject to variations due to speed of rolling, temperature, etc., and suitable margins must be allowed in the size of the motor for driving the mill, so that it can give sufficient power under such conditions, while at the same time it is not unduly large. Mr. Ablett.

I think the reason that the 3-phase motor with the 3-step pulley for driving merchant mills has proved wasteful is because many people, when considering a new mill, are disposed to think that three speeds only will fulfil all their requirements; they find when they get to work that this is not the case and that they want intermediate speeds and so have to use the slip resistance in order to obtain these speeds, which naturally wastes power. In certain cases where this system has been installed I understand that this is regularly done, and that the waste which is occasioned may be exemplified by the fact that such merchant mills are said to consume from 30 to 40 per cent. more units per ton than those which are provided with a variable-speed motor. Of course, if we could find an ideal case where three speeds only were required and where it was not necessary to reduce the speed in order to get the rolls to bite the bar under certain conditions or for other causes, the 3-step pulley arrangement would prove fairly efficient. The Ilgner system, of course, is advocated for large 3-high mills, that is to say, 20-in. mills and upwards, where it would hardly be practicable to use the 3-step pulley system, on account of the number of ropes, etc., which would be required to transmit such powers as are needed to drive mills of this description. Although, as Mr. Eckmann points out, from an electrical point of view the Ilgner system for driving 3-high mills is not very efficient; still, when due consideration is taken of the fact that a larger output can be obtained, that the bars are rolled faster and so there is not sufficient time for the temperature to fall much, it is found that less power is required to roll the steel, so that there is a considerable gain in this direction, as is shown by the low values for the kilowatt-hours per ton rolled which are obtained from such Ilgner-driven 3-high mills.

In Mr. Eckmann's remarks about the compounding of the so-called "Kramer" system, I think he has based the figures on the assumption that 5:1 speed variation is required, but in practice the usual speed variation for merchant mills is 2:1, or at the very utmost 3:1, so that the difficulties which he anticipates do not occur. I do not think that the efficiency of the electrical drive can be over-rated, provided that it is not obtained by too great a capital cost or by other attendant disadvantages. It is just as necessary that the electrical drive should be made efficient as that the various losses in the mill should be reduced as far as possible, so that the cost of rolling a ton of steel should be reduced to the minimum possible.

Mr. Ablett. With reference to Mr. Kaula's remarks, I did not deal with the multi-speed 3-phase motors consisting of a combination of cascade and pole-changing arrangements, because they are subject to the same disadvantages as the 3-phase motor and 3-step pulley arrangement, namely, that they only give certain definite speeds, and we are not able to obtain any speed over a large range of speed variation.

Mr. Yerbury, in saying that no hard-and-fast rule can be laid down for the comparative costs of electrical and steam or gas power for rolling-mill driving, and that each scheme must be considered on its own merits, has, I think, summed up the situation very completely. In Sheffield, where gas costs 11d. per 1,000 cub. ft., I expect that in certain cases gas is a formidable rival to electrical power, more especially in driving small mills rolling such light material that the power actually taken for rolling is a small percentage of the power consumed by the friction of the mill, so that the power demand is pretty constant. For driving larger mills, however, where the power may be subject to considerable fluctuations, the situation is completely different owing to the notoriously bad overload capacity of the gas engine.

As an example, a 350-H.P. motor would be found ample for driving a 12-in. merchant mill rolling up to 3-in. × 3-in. angles, 4-in. flats or 1½-in. rounds, under ordinary conditions; but to get the same output with a gas engine an engine of from 600 to 700 B.H.P. would have to be installed to take care of overloads, and the saving over electrical power with electrical current at 0·6d. per unit, effected by the gas engine, would not be sufficient to pay the interest on the extra capital expenditure on this engine with a mill working under ordinary conditions.

There are naturally many works where furnace gases are available for generating steam, particularly in iron works where steam boilers are regularly employed to raise steam by using the hot gases from puddling furnaces. There is also naturally a definite relation between the steam available from the puddling furnace boilers and the power required to roll and finish the iron produced by the puddling furnaces under definite conditions. It is often found that the steam raised from waste heat is insufficient to provide the power required, so considerable quantities of coal may have to be burned if the mills are driven by steam engine, and this is particularly the case in an iron works where a considerable quantity of steel is being rolled in addition to the iron, as the steel creates a large demand for power without increasing the waste heat available. For economical working it is necessary to use the waste heat, which constitutes the natural resource of an iron works, as economically as possible, and in several works it has been found that great savings have been effected by having, instead of a large number of steam engines scattered about the works, fed through long ranges of steam piping, electrical power generated in a high-pressure turbo-generator and driving the mills and the auxiliary machines electrically. This has enabled a greater quantity of power to be generated from a

definite amount of waste heat available, and has obviated the necessity of burning coal for raising steam. Mr. Ablett.

The 12,600-H.P. motor mentioned on page 614 of the paper, to which Mr. Burnand draws attention, is direct-coupled to the mill which it is driving; that is to say, it is coupled to one of the pinions by the usual form of crab, and the pinions are coupled to the roll wobblers by the usual arrangement of leading spindles and muff couplings. That this coupling does not present any problem out of the ordinary is shown by the fact that reversing mill engines, which can give powers up to 18,000 or 20,000 H.P., are coupled to the mills which they drive in a similar manner. The accelerating and reversing facilities that have been mentioned have been proved by tests, and as such rapid accelerations do not demand more than a small fraction of the motor-powers, they do not present a difficult problem. The 12,600-H.P. motor mentioned above only gives such powers as this when a bar is in the rolls, and so is working very intermittently as it is supplied through a flywheel motor-generator set, whose function is to ensure a steady average demand on the power station plant of less than 2,600 H.P. The use of such Ilgner plant does not create conditions requiring the installation of 12,000-H.P. turbines or generating plant of anything like this power. The coupling of a steam turbine to the flywheel motor-generator set presents many advantages, and is now receiving serious consideration in several quarters. If Mr. Burnand proposes that the variable voltage generator of the flywheel motor-generator set be a turbine-driven homopolar machine so that high speeds would be adopted, then there is the possibility that wire-wound flywheels would be required; but this is probably looking rather far into the future, as the homopolar machine has still to prove itself. It would be a matter of technical interest to see the series system installed for driving a reversing mill, but I cannot see that it would present any commercial advantage by reducing the cost of the installation.

In reply to Mr. Ellison's question, I do not think it necessary to use two motors to drive a 12-in. merchant mill, but I think it would be of advantage to do so, if large outputs are required, for in addition to making the speeds of the roughing and finishing rolls independent of one another, it would enable the roughing rolls to be placed in tandem with the finishing rolls without the complication of a rope drive and the disadvantage that in such a case a portion of the flywheel power may have to be transmitted through the ropes.

Mr. Wood has referred to a form of intermittent-slip regulator consisting of a liquid resistance which was worked by a boy stationed at it, so that the boy increased the motor slip as soon as he saw that a bar was about to be entered into the rolls. This form of slip regulator is, of course, almost an ideal one, because it anticipates the need for power, instead of coming into action after the increase in power itself has occurred, and the ideal slip regulator would be one governed automatically in such a way that it anticipates the need for power.

Mr. Ablett. I do not consider that we can assume that the loss in a properly designed rope drive would just about off-set the loss due to low efficiency of a slow-speed motor, but consider that the loss of the rope drive is much greater in such cases where the power varies greatly. I think this is evident when it is considered that the loss in the rope drive goes on continuously whether the ropes are transmitting their full power or not, while any loss due to lower efficiency of a slow-speed motor is a proportion of the power which the motor is actually giving, and not of that which it can give.

With reference to Mr. Rosher's remarks about Figs. 4, 5, 6 and 7 in the paper, these were drawn merely as illustrations of the behaviour of the flywheel and motor in a number of simple cases, in order to enable a better understanding to be obtained of the more complicated cases which usually occur in rolling mill work. It happens, however, that while these diagrams do not represent conditions which often occur in practice, yet some of these do represent the conditions obtaining in certain forms of tube mills.

Before condemning the gearing of a motor to the mill, I think it should be considered that, as before mentioned, there are 30 large reversing rolling mill installations at work in different parts of Europe, in which the motors give powers up to 10,000 or 12,000 H.P., and that in nearly every case the motor is direct coupled to the pinions so that half the motor power is transmitted through the pinions to drive either the top or the bottom roll, according as the motor is coupled to the top or bottom pinion, there being no flexible coupling between the motor and the pinions. In several other cases, these large reversing motors are driving through gearing, the pinion being direct-coupled to the motor. Each one of these reversing mill drives has worked very satisfactorily. There are also a considerable number of electric motors driving rolling mills through gearing, in England, which have worked very well. We, therefore, have a large number of cases on record where the motor is driving the rolling mill through gearing without any flexible coupling being interposed between the gearing and the motor and where the results have been very satisfactory.

The case which Mr. Rosher mentions of a sheet mill which is driven through spur gearing by a 250-H.P. motor is also interesting, and I should quite anticipate that it would be found necessary to insert a resistance in the rotor circuit of this motor. Before this resistance was inserted the motor would probably be giving very large overloads, and the effect of inserting the resistance would be materially to reduce these overloads. These overloads would naturally cause an increase of saturation in the magnetic circuit in the motor, which would be accompanied by a certain amount of noise, and I should think this very probably accounts for the grinding which was mentioned. Mr. Rosher has also mentioned the application of the pole-changing 3-phase motor, and the 3-phase cascade system to merchant mills where a variable speed is required. The chief objection to these devices is that they only give a few fixed speeds which in general do not prove sufficient to

meet the requirements of the mill, so that resistance would have to be inserted in the rotor circuits in order to obtain intermediate speeds, which naturally involves waste of power. As a merchant mill rolls the heavy sections at the low speeds, which require a greater turning moment than the smaller sections, which are rolled at a high speed, in general the motor driving a merchant mill has to be capable of giving the same power at all speeds. That is to say, the turning moments should increase as the speed falls. If a pole-changing motor, therefore, is employed, it would have to be a big machine of which the capital cost would naturally be high, in order to give the required power at the low speed. Both the pole-changing motor and the 3-phase cascade system suffer from the disadvantage that the power factors at low speeds are not good, which in some cases is a drawback, and the 3-phase cascade system suffers from the additional disadvantage that when it is being worked "cascade," the fact that the rotor of one machine is connected to the stator of the other makes the power factor in the rotor of the first machine bad, and as the power factor in the rotor circuit has a great influence on the turning moments which the induction motor can give, this tends to limit the overload capacity of the machines. Mr. Ablett.

The comparison of costs between a steam-driven and an electrically driven mill which Mr. Rosher mentions is very interesting, but I should suppose from the figures which he gives that this mill is one which is working very intermittently indeed, so that the upkeep charges of the steam plant form a large proportion of the total cost.

Dr. Smith has referred to the frequency changer as a means of obtaining variable speed from a 3-phase motor without loss of power. At the Hagen Cast Steel Works in Westphalia, as well as in several other places, such an arrangement is adopted for driving the merchant mills; possibly the following brief explanation of the system may prove interesting: The frequency converter generally resembles a rotary converter, but the field-poles have no winding. If a rotary converter is run at a synchronous speed and supplied with 3-phase current, it will give direct current at the commutator. If, however, the rotary converter is at standstill, 3-phase current will pass through the machine with unchanged frequency. If a rotary converter is run at speeds intermediate between synchronous and standstill, then the frequency at the commutator is proportional to the amount which the speed is below synchronous speed. It is therefore possible to couple such a frequency converter to a 3-phase motor, to connect the commutator of the frequency converter to the slip rings of the 3-phase motor, and to connect the slip-rings of the frequency converter to the supply mains. If, then, the main 3-phase motor is to be run below speed, the frequency converter takes power out of the rotor circuit, converts this power from low frequency back to the frequency of the supply, and returns it to the supply mains, so that the power is not wasted. When such a frequency converter is used, the main 3-phase motor can run above synchronous speed, but in this case energy is taken from the supply system and given to the rotor circuit, and it is usual in a frequency

Mr. Ablett. converter drive to choose a synchronous speed, so that it comes about the middle of the speed range over which variation is desired.

Mr. Milns has mentioned that he usually finds that the cost of working is the determining factor. This, of course, is so in certain cases, but among the large steel works the question of output is also a very important factor, too, because where large outputs can be obtained the cost of working is naturally cheapened, as the establishment charges are reduced. Mr. Milns has also referred to the importance of eliminating all sources of friction as far as possible when converting an old mill to the electric drive, and this is a point in which I am in most complete agreement. I think, however, that with new mills the question of reducing the friction as far as possible has not been given as much attention as it might have had in the past, but there is no doubt that as electrical driving finds a greater adoption and the power absorbed by the mills can be easily and accurately measured, the losses due to friction will become more and more appreciated and measures will be taken for their prevention.

Mr. du Pasquier has called attention to the fact that in the conclusion on page 621 of the paper the slow-speed motor is not debited with any slip loss. This has been done purposely, as I had in mind one of the various types of slow-speed 3-phase motors which can be arranged to fall in speed as the load increases without incurring any loss thereby. In the case of the 600-H.P. motor driving a sheet mill by means of twenty 2-in. ropes, which I mentioned, the flywheel was running at a slow speed, being direct coupled to the mill and was not on the motor shaft, so that the flywheel was not discharging through the ropes. As Mr. du Pasquier remarks, the number of ropes provided certainly appears excessive, but the plant was put in to the designs of a well-known mechanical engineering firm who claim a very wide experience in rope driving. I have recently collected all the data I could about the rope drives for half a dozen or so sheet and tinplate mills, and I find in every case that the drive was much over-roped, quite in the proportion of the case indicated above, presumably to deal with the large instantaneous powers which may occur. This, as I have already pointed out, largely accounts for the large rope losses. I might take this opportunity of saying that Mr. du Pasquier is mistaken in thinking that I have recommended a rope drive for a new sheet mill on the north-east coast.

I do not think that I have dealt unduly hardly with the 3-speed rope pulley drive for obtaining three speeds for a bar mill when an ordinary 3-phase motor is used. It is found in practice that with this drive three speeds are not sufficient to meet with the various requirements of the mill, and that for rolling many sections intermediate speeds have to be obtained by adjusting the ropes for the next higher speed and then reducing the speed by means of the slip resistance, which naturally entails a waste of power. For this reason I do not consider that the 3-speed rope pulley is the commercial solution of

Mr. Ablett.

this particular engineering problem. It is true that it is an arrangement of which the capital cost is very cheap, but, on the other hand, the working costs are high, and in most practical cases I have little hesitation in saying that if the increase in the working costs involved by using this arrangement are capitalised it will be found cheaper to have adopted a more efficient drive though it may have been more expensive in first cost. For this reason I consider the 3-speed rope-pulley drive as commercially unsound unless the cost of power should be exceptionally low.

Mr. du Pasquier has offered some criticism of the variable-speed scheme which is illustrated on page 619, and seems to prefer the use of a direct-current motor, which is supplied with current through a rotary converter and a transformer for driving a merchant mill where 3-phase current only is available. I am not in agreement with this, because in the case of the scheme shown on page 619 the main 3-phase motor is the only machine which is really necessary to drive the mill, and the rotary converter and the direct-current motor can be regarded as refinements introduced for the sake of economy. If anything should go wrong with either of these two machines, then the mill can still be run without interruption by the main 3-phase motor, the speed being reduced by means of a starter, which though uneconomical is good enough for a temporary expedient. The variable-speed 3-phase scheme, therefore, may be regarded as a one-link chain, as it depends for its reliability only on the plain 3-phase motor, which is in every respect a well-known and well-tried machine. On the other hand, if a transformer, a rotary converter, and a direct-current motor be installed to drive such a mill the full power must be transmitted through each one of these mechanisms, so that each one of these three pieces of apparatus is indispensable to the working of the mill, and if for any cause any one of these three should fail then the mill will be stopped. This must hence be regarded as a 3-link chain which is no stronger than its weakest link. Mr. du Pasquier has also referred to the case where there are a number of merchant mills in one works for which 3-phase current only is available. I would hardly suppose, however, that he would propose to convert the 3-phase current into direct current in a single transformer and single rotary converter in order to supply these mills, as this would make the whole works dependent on two machines, the failure of either one of which would be to bring the plant to a standstill. Mr. du Pasquier also refers to the use of the system illustrated on page 619 of the paper for driving sheet mills, and draws the conclusion that the use of this system is commercially unsound, on the supposition that it is used to save rheostatic losses only, the average slip being of the nature of 5 to 7½ per cent. If the average slip with a sheet mill were really as small as this I should have no hesitation in agreeing entirely with Mr. du Pasquier's conclusion, but in practice it is often found that much larger slips than this have to be considered, and in addition there are a number of other considerations which, when taken into account,

Mr. Ablett. make the proposal very sound indeed when worked out on a basis of pounds, shillings, and pence.

With reference to Mr. Taylor's remarks about the overload capacity of electrical plant and the advisability of allowing mill motors to carry such overloads, it may be mentioned that direct-current motors are being regularly built for 300 per cent. overload and more, and if such large variations of power are not objectionable to the supply system, then it is obviously right to install a motor of such a large overload capacity and allow the power to vary to this extent, using only a light flywheel, or else restricting the fall in speed to enable the flywheel to take effect, as in the one case greater economy is obtained and in the other case greater output can be obtained. The cost of the electric motor, however, will naturally be somewhat increased.

Dr. Kapp has referred to the practice which has obtained in a number of places on the Continent of providing cast-iron cases for the high-speed flywheels of Ilgner motor-generator sets and of exhausting the air from these cases so that the flywheels run in a vacuum. It has been found, however, that there is little to be gained by this, as a very large proportion of the total power which is saved by running the flywheels in a vacuum is absorbed in maintaining the vacuum. In the case of high-speed Ilgner flywheels the windage forms by far the greatest proportion of the loss, and it is found in practice that most of this windage is produced by the rim of the wheel, so that if a light metal cover is provided over the rim of the wheel the windage loss can be reduced to reasonable proportions. Dr. Kapp has also referred to the possibility of using the commutator 3-phase motor for driving rolling mills, and it may reasonably be expected that this machine will find considerable adoption in the future for this purpose.

Mr. Orsettich has asked how Figs. 4, 5, 6, 7, and 8 were obtained. The first four of these were drawn to illustrate generally the behaviour of a motor and flywheel under various conditions. They are drawn from theoretical considerations and do not represent the results of practical tests. Fig. 8, however, is drawn to show the practical conditions of a rolling mill and is drawn out from the results of practical tests, many of which have become available as numerous electrically driven rolling mills are set to work. In the case which Mr. Orsettich mentions that he has investigated, which I take to be the question of using the Ilgner system for driving a large 3-high mill, I think there must have been something very exceptional in the conditions if he found that the use of the Ilgner system would increase the total cost of the plant by from 20 to 25 per cent.

The suggestion which Mr. Moffett makes, with regard to the use of a slipping clutch for transmitting the power from the rolling mill motor to the mill, is very interesting, and it would be of great interest to see it applied in practice, and particularly to obtain some definite data as to whether the frictional losses in the slipping clutch were considerable or not.

Reply to the Discussion before the Newcastle Local Section.

Mr. Rothera.

Mr. L. Rothera (*on behalf of the author*): Mr. Stoney raised the question as to the comparative efficiency of the Ilgner plant as compared with a 3-phase motor using a slip resistance. The overall efficiency of the Ilgner system, as a rule, varies between 60 and 70 per cent., which, as Mr. Stoney points out, is somewhat less than a 3-phase motor with a slip resistance, but at the same time, as the author points out in the paper, when using this type of plant an increase in output from the mill of from 20 to 30 per cent. can be obtained. Owing to the more rapid rolling thus obtained the temperature at which the metal is worked remains higher, so that, although from theoretical considerations the 3-phase motor might be more economical, it is found in practice that the consumption of energy per ton rolled is less in the case of the Ilgner plant. With regard to the doubt that Mr. Stoney expressed as to the equalising effect of the load on the power station due to the installation of the electric drive for three or four rolling mills, this effect was clearly shown on one of the slides during the lecture, which showed a case in which three large mill motors were supplied from the same power station. In the case of another mill, where there are three large motors installed of a total power of 1,300 H.P., and a considerable number of small motors taking approximately 200 H.P. constant power, it is found that the maximum peak load on the station does not exceed 630 k.w., which shows to what an extent the equalising of the load occurs. The conditions occurring in the case of a tramway system are not in any way comparable with the conditions which a rolling mill produces, as in the latter case a considerable number of peak loads occur per minute, whilst in the case of a tramway system a car will not be started or stopped nearly so many times.

In reply to Mr. Marshall's objection to the names suggested by the author for the two types of regulators, the author admits that the names perhaps might be improved upon, but at the same time it must be pointed out that the author's suggestions will do equally well for the case of a direct-current or alternating-current system, whereas the terms "fixed resistance type" and "variable resistance type," put forward by Mr. Marshall, although excellent for alternating-current work, are not suitable for direct-current work. Another point to be remembered is that, when putting forward systems to men whose knowledge of electricity is limited, the author's terms have the advantage that attention is drawn to the fact that a slip is produced with an increase of load, thus conveying the impression that power is being taken from the flywheel. Mr. Marshall also suggested that the efficiency of a motor with a slip regulator was better than the variable speed set described in the paper. Assuming an ordinary 3-phase motor with an efficiency of 92 per cent., and introducing into the rotor circuit of this motor a slip resistance designed for 20 per cent. drop in

Mr. Rothera.

speed, the efficiency at full load of such a motor would be approximately 72 per cent., whereas a variable speed set running at a medium speed of 125–250 revs. per minute could be designed for an overall efficiency at full load of 88 per cent., and even in the case of a slow-speed set running at about 40 revs. per minute, the overall efficiency would not be less than 85 per cent.

Dealing with the question of systems of charging adopted, the author is aware that a charge on the instantaneous peak loads is not the usual practice, but when contrasting the effect of various systems of charging on the design of motor and flywheel, he thought it advisable to call attention to all systems for purposes of comparison. A member brought forward the point that, in the case of a private power station, what was particularly wanted was some means of keeping up the power factor. There is, perhaps, a tendency to attach too much importance to this point, due to the fact that experience has been gained in the past on stations supplying a large proportion of lighting as well as power where a bad power factor has a prejudicial effect on the voltage regulation of the supply. In the case of a power station supplying load to a large works, it may be found cheaper to install an entirely separate generator for dealing with the lighting load, and somewhat larger generators for the power load, than to employ special plant for improving the power factor of the motor system. In such a case there would be no necessity to trouble particularly about the power factor.

Mr. Hanks raised the question as to the possibility of supplying a contactor system in place of the liquid intermittent-slip regulator shown in Fig. 10. The method proposed by him was very ingenious, and it would be interesting to know what time lag such a system of coils would have, in view of the fact that a large number of relays have to come into operation. As no such systems have been put into operation in the case of rolling mills, it is reasonable to suppose that it is found in practice the time lag for this type of apparatus is excessive for dealing with the very short heavy peak loads occurring in rolling-mill work.

Dealing with the points raised by various speakers with regard to the question of rope losses, the figures put forward by Mr. Ingham are of great interest. The author has investigated a large number of rope drives in existence, and finds that in practically every case sufficient ropes have been installed to transmit twice the normal power of the motor. This design may be wrong, but it has been the practice up to the present. The author points out that a rope drive involves a 10 per cent. loss of power. It is perhaps better to say that a rope drive involves a loss of 5 per cent. of the power which the ropes are designed to transmit, which, in view of the fact that the ropes have been normally designed for transmitting double the normal power of the motor, represents a loss of 10 per cent. on the full-load power of the motor. Various speakers gave particulars of the losses occurring in rope drives in the Lancashire cotton mills, and the figures stated the rope loss in

such drives was from 3½ to 4 per cent. It is well to point out that the case of a cotton mill is very different to that of a rolling mill, since in the former case a practically steady drive is obtained, whereas the power in the latter fluctuates rapidly between very wide limits. It would be of interest to know how the above figures for rope losses were obtained, and it appears probable that the method employed was to indicate the engine running light. This method is open to very considerable errors, due to the small area of the indicator diagram, and doubts as to the mechanical efficiency of the engine. The only accurate method of obtaining such losses would be to install a motor of just sufficient power to drive the ropes round light, and to measure the input electrically. Mr. Ingham stated that for a motor of 1,000 H.P., the average load of which would be in the neighbourhood of 500 H.P., he would install ropes designed to transmit a normal power of 800 H.P. As a motor of this power might easily be called upon to deal with overloads up to 2,000 H.P. at frequent intervals, it appears to me that the life of the ropes would be very small, and, in view of the fact that in the case of a rolling mill absolute continuity of the drive is essential, it would appear to be false policy to install ropes stressed to too high a limit, and I am of the opinion that most rolling mill engineers would prefer to lose the additional power in transmission losses, to the fear that the ropes might fail at any moment.

Mr. Rothera.

Proceedings of the Five Hundred and Thirty-Second Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, 25th January, 1912—Mr. S. Z. DE FERRANTI, President, in the chair.

The minutes of the Ordinary General Meeting, held on Thursday, 18th January, 1912, were taken as read, and confirmed.

Messrs. M. Rosenbaum and M. G. Bland were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Members.

Minor Meek Davis.
Augustine Davy.
John William Lieb.
James Lyman.
John Alexander McLaren.
George William Malcolm.
Walter John D. Partridge.
Henry Rottenburg.

As Associate Members.

Frederic Clement Aldous.
Eugene Nial Allan.
Dhiranga Nath Banerji.
William Alfred Barnett.
George James Beattie.
Stanley William Cobban.
William Joseph Cockshott.
Stratten Holmes.
Thomas William S. Hutchins.
Gerard Herman Langeler.
Arthur Sanderson Robertson.
William Ellerd Styles.
Tom Taylor.
John Godfrey P. Thomas.
Kenneth John Thomson.
John Kilner Wells.
Henry Wilson.
Russell Stuart Wright.

As Associates.

Harold Ernest Goody.
Arthur Cecil Livesey.
Charles Smart Roy.
Montague Harold Vickerman,
Oscar Candish Waygood.

As Students.

Victor Arnold-Jones.
John Bates.
Leslie J. Brennan.
Reginald Morse Charley.
Archibald Godfray Colston.
Charles B. Colston.
Leslie J. Fathers.
William George France.
Charles Frederick Goodale.
Sidney Gudgeon.
Heron Hudson.
Henry John Lee.
A. W. Roy Macpherson.
Cecil Edmund Maguire.
Hilary Strina Marquand.
Dundee Sarangapany Naidu.
Stanley Osborn.
Stanley Frederick Parsons.
Albert Pigg.
Arthur Charles Roberts.
Arthur Victor Scratchley.
Cecil Graham Shaw.
Alexander Shearman.
Douglas Nuttall Sladen.
Leonard Warren Smith.
George Henry Stade.
Antonio Martins Teixeira.
Ernest Edward Tipper.
Walters Clements Tisch.
James Smith Walker.
Ernest Alfred Warden.
Stanley Hugh Winkley.
George Herbert Wood.
Raymond David Wooster.

The following paper, "The Heat Paths in Electrical Machinery," by Harold D. Symons, Associate Member, and Miles Walker, Member, was read and discussed (see page 674), and the meeting adjourned at 9.37 p.m.

THE HEAT PATHS IN ELECTRICAL MACHINERY.

By HAROLD D. SYMONS, Associate Member, and MILES WALKER, Member.

(*Paper first received 9th November, received in final form 29th November,* 1911. *Read before* THE INSTITUTION *on 25th January,* 1912, *and before the* MANCHESTER LOCAL SECTION *12th December,* 1912.)

SUMMARY.

The paper deals with methods of predetermining the temperature rise in electric machinery. Data are given of the heat conductivity of insulating materials. The methods of carrying away heat by the circulation of air are discussed, and there is given an account of experiments made to determine the amount of heat absorbed by air un er various conditions as to temperature and velocity in passing over coils and through ventilating ducts. The heat conductivity of punchings in actual machines is also considered.

If we wish to get the largest possible output from an electric generator or motor of given cost we must make a very close study of the possible methods of carrying away the heat which is produced in the iron and copper. The heat produced in any part (be it from I^2R loss or iron loss) has a definite path from the point of origin to the place where it is thrown out from the machine. Thus some of the I^2R losses in the armature conductors may have only to pass through a certain thickness of insulation to the air surrounding the coils, while the heat generated in the copper in the slots passes through the insulation to the iron where it meets with the heat produced in the iron, and both together are conducted to the ventilating ducts and carried by the air to the exterior.

We can imagine lines of heat-flow drawn through the machine which follow everywhere the paths of the heat from the point of origin to the point of discharge. At some points there may be constrictions in the path which it is desirable to avoid, at others the heat stream flows easily without undue temperature gradient. Everywhere at right angles to the lines of heat flow we can imagine isothermal surfaces constructed which enclose the points of highest temperature.

If we are to even out these surfaces and lower the maximum temperatures, we must consider closely all the methods by which the heat is conveyed, whether it be by conduction, convection, or radiation.

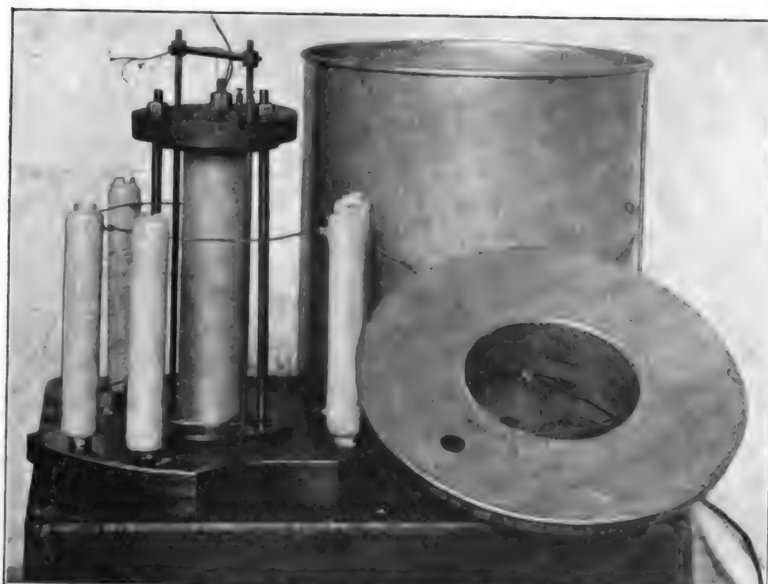


FIG. 1.—Apparatus for measuring Heat Conductivity.

The metals being good conductors, any heat produced in a mass of copper or iron distributes itself easily over the whole mass, but the insulating materials being poor heat conductors often cause excessive temperatures within the coils they enclose. It is desirable that the designer should have specific data as to the heat conductivity of every part of the machine in order that he may know what difference of temperature to expect between any two points in the heat path.

A good deal of useful work has been done on the measurement of temperatures inside shunt coils,* on the heat conductivity of iron punchings † at right angles to the plane of lamination and along the laminations; on the passage of heat from revolving cylinders ‡ to the surrounding air and on the passage of heat from various kinds of surfaces to air; but the authors have not been able to find any direct data on the heat conductivity of electric insulating materials mounted in the same way as one usually finds them in electrical machines. They therefore thought that it would be worth while to make measurements both of the specific conductivity of the commonly employed insulating materials and of the effect on the conductivity of introducing the air-spaces and gaps such as are often unavoidable in electrical machines.

Two classes of tests were made. First a test by means of laboratory apparatus on the specific heat conductivity of materials mounted in different ways. Secondly, tests made on electric generators under actual running conditions.

THE HEAT CONDUCTIVITY OF ELECTRIC INSULATION.

For measuring the heat conductivity of materials in flat sheets probably the best method § is that employed by Mr. Bacon. This method was used by the authors for pure mica and for presspahn. But where the heat conductivity of wrappings of tape and wire are to be measured it is more convenient to adopt a type of apparatus like that depicted in Figs. 1 and 2.

The materials 1–1 are wrapped on a long copper cylinder 2–2 and the heat passed from the inside through the insulation to an oil bath 3–3 on the outside. The temperature of the outside of the cylinder of insulation is measured by thermo-couples placed in shallow channels in the copper surface of the cylinder, the wires from the thermo-couples being brought out to the top of the apparatus, shown at 4–5–6. The temperature of the outside of the insulation is measured by thermo-couples placed

* E. H. Rayner, "Report of Temperature Experiments," *Journal of the Institution of Electrical Engineers*, vol. 34, p. 613, 1905. G. A. Lister, "Heating Coefficient of Magnet Coils," ibid., vol. 38, p. 399, 1907.

† O. Ludwig., *Mitteilung und Forschungsarbeiten*, Heft 35 and 36, p. 53. T. M. Barlow, "Heat Conductivity of Iron Stampings," *Journal of the Institution of Electrical Engineers*, vol. 40, p 601, 1908. R. D. Gifford, "Influence of Various Cooling Media upon the Rise in Temperature of Soft Iron Punchings," *Journal of the Institution of Electrical Engineers*, vol. 44, p. 753, 1910.

‡ E. Hinlein, *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 55, p. 730, 1911.

§ F. Bacon, "The Testing of Heat Insulating Materials," *Engineering*, vol. 90, p. 396, 1910.

between the outside surface and a sheet of copper which was tightly wrapped around the whole. The insulation is thus placed between two surfaces of known temperature under conditions which can be made to imitate as closely as we like the conditions obtaining in the slots of electric machines.

The heat is supplied to the inside of the copper tube by means of a resistance coil 7, embedded in asbestos insulation. This resistance coil is concentric with the copper tube, and the space between them is filled with tin solder which serves to conduct the heat to the copper. The inside surface of the tube was tinned before pouring in the melted

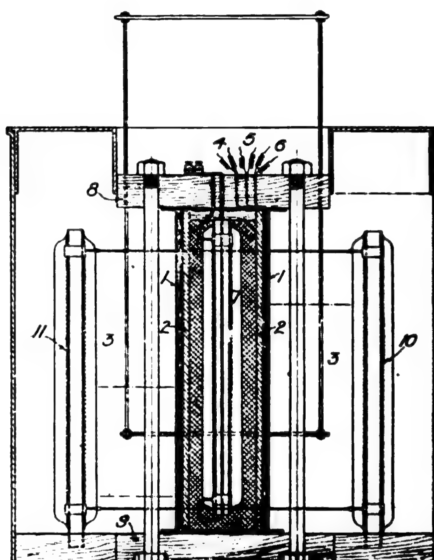


FIG. 2.—Section of Apparatus for Measuring Heat Conductivity.

solder to ensure a perfect and uniform junction of the metals. A thick copper tube heated in this way maintains itself at a fairly uniform temperature over the greater part of its surface even though the cooling conditions of various parts differ considerably.

The ends of the copper tube are flanked with leather washers and two thick cheeks of treated wood (8 and 9), to minimise the escape of heat. It is calculated that the loss of heat at the ends is equal to 0·015 calorie per second per degree of difference between the inside and outside temperatures. In most of the experiments this amounted to about 3½ per cent. of the total heat flux, so that even if there is a considerable error in the estimation of this end loss the final error due to this cause is not more than ½ per cent.

In some of the experiments the copper tube and insulation were immersed in a bath of oil which was well stirred during the whole of the test so as to keep the outside of the insulation at as uniform a temperature as possible. The oil was contained in a large tank which offered a cooling surface of 750 sq. in., so that it would radiate all the heat supplied without an excessive rise in temperature. A number of resistance coils 10–11 were inserted in the oil, and by means of these the temperature of the oil could be maintained at any required value. These resistances are also of use in shortening the time taken to arrive at a steady state in the temperature distribution. If, for instance, it is intended in any particular experiment to supply a total of 100 watts, then as we know from previous tests that the tank will finally settle down at 25° C. above the air temperature, the tank is brought up quickly to 25° C. by a large current through the resistances, and as soon as the temperature is reached the current is cut down to the value which keeps the temperature steady.

The method then of carrying out a test on any insulating material is as follows: The material is wrapped around the copper cylinder, the thermo-couples for measuring the temperature of the outside are then fixed and wrapped over with the exterior copper sheet, the insulation is trimmed off the ends of the cylinder so as to fit well against the leather washers, the two wooden cheeks are fitted to the end of the cyclinder and held firmly by long bolts. The whole is then immersed in the oil tank and the wires to the various couples connected to a multi-way switch and to the cold thermo-couple immersed in a bath of oil whose temperature is kept steady and measured by means of a thermometer. The difference of temperature between the hot and cold junctions was measured by one of R. W. Paul's millivoltmeters. This instrument, with a suitable resistance in circuit, will give the temperature in °C. direct if we employ couples composed of metals such as iron and eureka which have an almost straight-line law over the range covered by the experiments. A known current at a known voltage is then passed through the resistance coil inside the copper tube, and the temperature of the oil in the bath is raised to the point at which it will remain steady under the conditions of the experiment. Readings of the temperature are taken at frequent intervals, and when they are found to be steady we know that the heat is being conducted through the insulation at the same rate as it is being supplied. The total heat flow through a certain area and thickness of insulation being known, and the difference of temperature at the two sides being known, the thermal conductivity can be calculated.

In other experiments the copper tube and insulation were placed in a wooden frame by means of which two draughts of air could be blown on to the material under test from opposite sides, as indicated in Fig. 3. A photograph of the apparatus is shown in Fig. 4. The intensity of the draught of air was measured by means of anemometer and checked by measurements of the temperature of the air going in and the air

TABLE I.

Rope Paper (Untreated.)

Twenty layers, each 0·014 cm. thick. Total thickness, 0·283 cm.
Outside area, 478 sq. cm. Inside area, 450 sq. cm.
Mean area, 464 sq. cm.

Time.	Inside Junction. °C.				Outside Junction. °C.				Cold Temperature. °C.	Amperes.	Volts.
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.			
Hrs. Mins.											
4 15	117·0	115	120	121	68	63	64	71	21·3	5	155
4 45	106·0	106	110	111	64	58	60	68	21·8	5	155
4 55	106·0	103	109	110	62	57	59	67	22·0	5	155
5 05	104·0	102	108	109	61	57	59	66	22·0	5	155
5 15	103·0	102	106	108	61	56	58	66	22·1	5	155
5 25	104·0	102	106	107	61	57	58	65	22·1	5	155
5 35	103·5	102	105	106	61	56	58	66	21·1	5	155

coming out. This apparatus, besides giving measurements of the heat conductivity of insulation, gives us specific data for the cooling of surfaces when subjected to a draught of this kind under conditions somewhat resembling the conditions obtaining in some electrical machines.

Table I. gives a typical set of readings for one test, and shows the degree of variation occurring in the different couples from time to time.

Table II. gives the heat conductivity of various insulating materials as measured in the manner described. The first and second columns give the material and the state in which the material was tested. The third column gives the thickness of the piece under test; the fourth

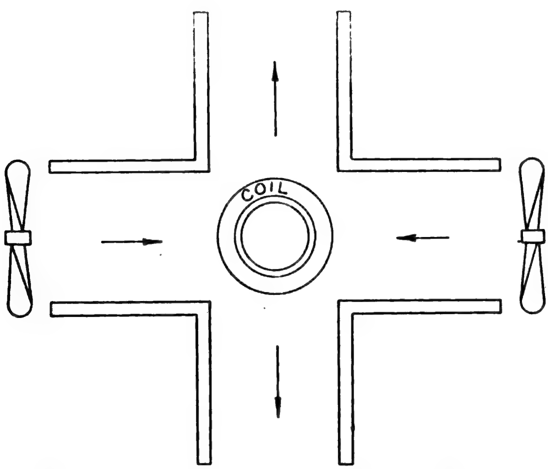


FIG. 3.—Plan of Apparatus for Cooling Coils or Rolls of Insulation by means of a Current of Air.

and fifth the temperatures of the inside and outside of the insulating tube; the sixth the mean temperature; the seventh the watts per square centimetre of surface; the eighth the heat conductivity in gram calories of a centimetre cube of the material per ° C. difference of temperature between opposite faces of the cube. The ninth column gives the conductivity expressed in watts per square centimetre, and the tenth column gives the watts per square inch passing through a 1 in. cube of the material for 1° C. difference of temperature between opposite faces of the 1 in. cube.

It was found that all the cellulose materials such as cotton, paper, etc., had a considerable temperature coefficient. The heat conductivity at a temperature of 100° being about 12 per cent. higher than at 30° C. The heat conductivity of mica was not found to change between 20° and 100° C.

Of all the fibrous materials commonly used in insulation the one having the highest thermal conductivity is empire cloth pressed into a solid mass free from air-spaces. This is probably because the fibres of the empire cloth are completely filled with oxidised varnish, whereas many of the papers, even when closely compressed, contain air-spaces.

The difference in the conductivity obtained by winding the insulation on the copper cylinder very tightly and by winding it on loosely was very marked.

It was found that micanite built up in the form of tubes containing about 11 per cent. of shellac has a very poor conductivity as compared with pure mica.

Effect of Air-space in causing Resistance to Passage of Heat.

Very often a field coil insulated on the inside with layers of insulating material does not fit tight upon the pole, so that a short

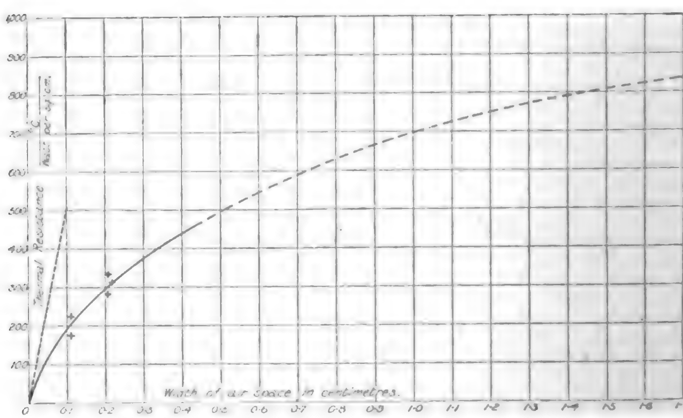


Fig. 5.—Thermal Resistance of Air-spaces of Different Thicknesses.

air-space exists between the insulation and the iron of the pole. It is interesting to inquire how far this air-space hinders the passage of heat.

A number of experiments were made, in which air-spaces of different thicknesses were made between the copper tube in the testing apparatus and the insulating tube. These spaces were made by winding twine of different thicknesses in a wide spiral round the tube, and then winding the insulating material above the spiral. The thickness of the twine gave approximately the size of the air-space. It is to be expected that a very narrow air-space will have a greater thermal resistance per centimetre of thickness than a wider air-space, and as the space is widened out we come at last to a constant resistance for 1 sq. cm. area of surface) which is the reciprocal of the cooling

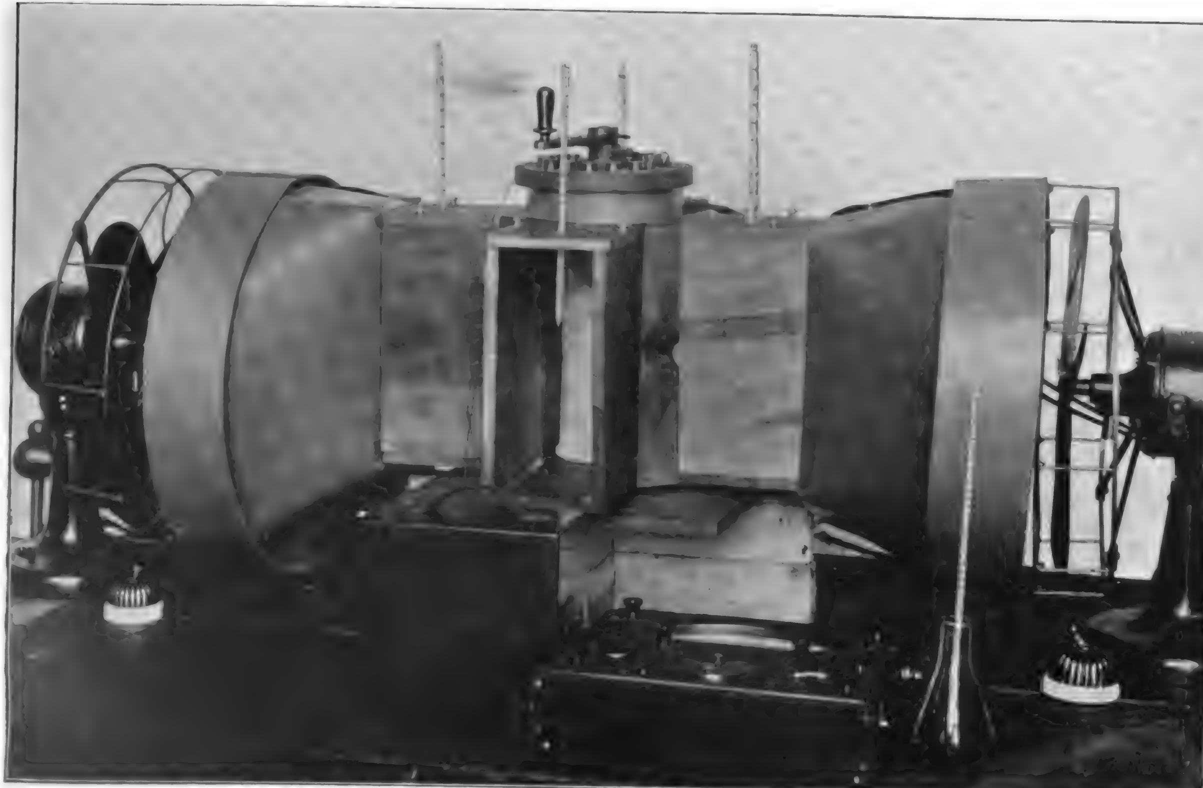


FIG. 4.—Apparatus for measuring the Cooling Coefficients of Coils at different Air Velocities.

constant ($h = 0{\cdot}0011$) for surfaces exposed to still air. The values obtained by our experiments do not agree very well with one another, as will be seen from Fig. 5, in which they are plotted. Still we may arrive at a fairly correct curve by the following method :—

The thermal conductivity of perfectly baffled air is 0·0002 watt per cubic centimetre per degree, so that the resistance of 1 sq. cm. of air-

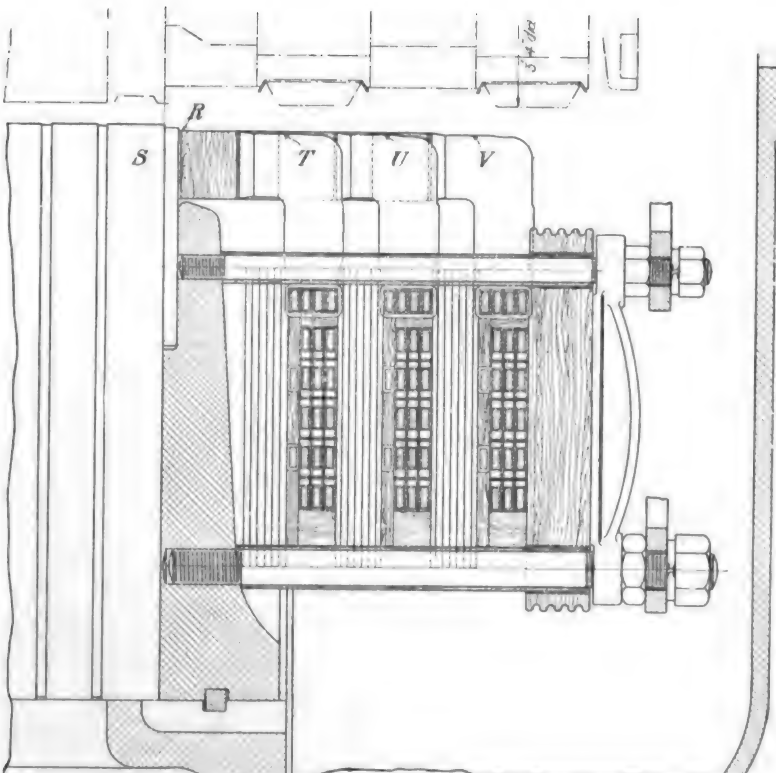


FIG. 6.—Positions of Thermo-couples for Test on the Heating of Armature Coils.

space 1 mm. thick would be 500. Here the units are chosen so that the thermal resistance has the same value as the difference in temperature, at the opposite sides of the space, divided by the watts per square centimetre passing across the space. If, therefore, we draw the dotted line shown in the figure through zero to the point 500 for an air-space 1 mm. that line must be a tangent to the correct curve. Taking the points indicated by our tests as a guide and remembering that the curve must

be asymptotic to the horizontal line at the value 900 $\left(\frac{1}{0{\cdot}0011}\right)$ we get the curve shown. There is no doubt that for wide air-spaces the resistance will depend on whether the space is vertical or horizontal,* and if vertical it will depend on the number of horizontal baffles. In our case the air-spaces were vertical and the pieces of twine which would have acted as baffles were spaced about ½ in. apart.

Let us now see how this curve can be employed in practice. Suppose that we have a field coil which is insulated on the inside next the pole with treated fuller board of a thickness of 0·2 cm. From Table II. we find the thermal conductivity of this material (in watts per square centimetre, etc.) is 0·0014. The thermal resistance of 1 sq. cm. is therefore $0{\cdot}2 \div 0{\cdot}0014 = 142$, so that if there were no air-space and we were passing to the pole 0·15 watt per square centimetre the difference in temperature of pole and coil would be only 21·3° C. If now we introduce an air-space of 1 mm. whose resistance from Fig. 5 is about 200, the total resistance is raised to 342 and the difference in temperature for the same heat-flow would be 51·5° C.

Experiments on Machines.

Heating of Armature Coils.—A test was made on a 5,000-k.w. 3-phase generator by means of thermo-couples placed in the armature coils during the course of construction. Fig. 6 shows the arrangement of the armature coils; the position of the thermo-couples is indicated by the letters R, S, T, U, V. Junction R gave the temperature of the copper inside the slot; S the temperature of the iron surrounding the slot; T the temperature of the outside of the coil on the part exposed to the air; U the temperature of the copper in part of a coil projecting 6 in. from the iron; V the temperature of the copper in part of a coil projecting 9 in. from the iron. The generator was run at full speed with the armature short-circuited, the field current being increased until the armature current was 328 amperes. The run was continued until the temperatures of all parts were constant. The table below gives the degrees rise above the temperature of the air admitted to the machine (23° C.).

° C. Rise.
R = 39·0
S = 18·4
T = 24·6
U = 38·0
V = 34·4

Fig. 7 gives the arrangement of the conductors and insulation in the slot. It is drawn full size. Each conductor, which consisted of two copper straps each 0·45 in. × 0·2 in., was insulated with tape and mica, a piece of mica 0·03 in. thick being added as a spacer. All four

* F. Bacon, *Engineering*, vol. 90, p. 396, 1910. He found that an air-space 1½ in. wide had a resistance twice as great when horizontal as when vertical.

Thermal Conductivity.		
er Square Centimetre per ° C. of ence of Temperature per Centimetre Length of Path.		er Square Inch per ° C. of Difference of Temperature per Inch Length of Path.
Calories per Second.	In Watts.	In Watts.
8	9	10
·000604	0·00249	0·00634
·000410	0·00170	0·00420
·000278	0·00115	0·00292
·000341	0·00142	0·00371
·000405	0·00170	0·00420
·000339	0·00140	0·00350
·000500	0·00209	0·00530
·000350	0·00145	0·0037
·000870	0·00360	0·00915
·000246	0·00103	0·00260
·000293	0·00120	0·00310
·000350	0·00146	0·00370

conductors were impregnated with gum and wound over with empire cloth and mica to a thickness of 0·13 in. The whole was then wound with linen tape. The total thickness of insulation amounted to 0·177 in. The various insulating materials were then present in the following proportions: Empire cloth, 0·07; mica, 0·03; varnish and air, 0·02; paper, 0·017; tape, 0·04. The heat conductivity of the insulation is easily calculated from the above figures. The total loss in the copper conductors per foot run of coil was 27·2 watts. In calculating this, allowance has been made for the rise in temperature of the copper due to the eddy currents * produced in the conductors. The difference of temperature between the copper and iron is 20·6° C, and the

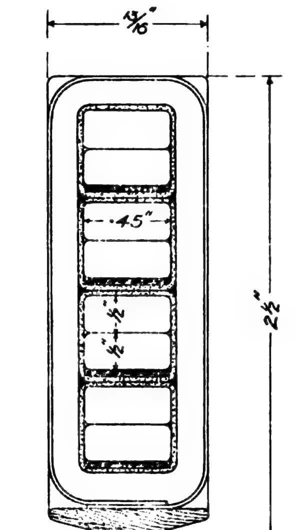


FIG. 7.—Arrangement of Insulation in Heat Conductivity Test.

mean perimeter 5·3 in., so that the total area of insulation per foot run is 63·5 sq. in. With 27·2 watts per foot run this gives just over 2·34 sq. in. per watt. The specific conductivity for heat of the insulation works out at 0·00145 watts per centimetre cube per degree. This conductivity is considerably lower than the figure (0·002) found from tests on empire cloth and mica wound on a copper cylinder with the fewest possible air-spaces, as can be easily understood.

With coils of rectangular section wrapped with empire cloth and mica, or paper and mica, in the ordinary method, one may expect to have a heat conductivity not higher than 0·00145 watt per cubic

* A. B. Field, *Transactions of the American Institute of Electrical Engineers*, vol. 24, p. 761, 1905.

centimetre per degree. This figure is useful in enabling us to calculate the difference of temperature between the copper conductors in a slot and the surrounding iron, and checks very well with other results found in practice. For instance, on the armature of a direct-current generator whose conductors were insulated with manilla paper and mica to a thickness of 0·16 cm. The temperature rise after a full-load run under conditions which made the square inches per watt 0·9, were as follows: Internal copper, 41°; iron, 22°. If we use the figure 0·00145 watts per cubic centimetre per degree, we would obtain a temperature rise of copper above iron of 16°.

CONDUCTION OF HEAT ALONG CONDUCTORS.

It sometimes happens that the copper conductors on an armature or field magnet are grouped together so closely that very little air can circulate between them, and the total cooling surface of the group is too small to dissipate the heat generated in it. In this case one relies mainly for cooling upon the conduction of heat along the conductors to parts of the coils where the cooling conditions are better. A good illustration of this case is offered by the end windings of a two-pole field magnet for a turbo-generator, such as is shown in Fig. 8. These end windings are completely covered in by a steel end-bell, so that in any case the air would not circulate well between individual coils, and to avoid the accumulation of dirt it is sometimes found advisable to fill the interspaces with suitable insulation. A great proportion of the heat generated in these end windings is conducted along the copper into the parts of the coils lying in the slots, and from thence it is conducted into the iron of the field magnet.

The flow of heat from the centre of the coil to the cooler parts can only occur if there is a considerable temperature gradient in the end windings. It is necessary sometimes to calculate what this temperature gradient will be, and what the maximum temperature rise will be in the centre of the group. The problem is somewhat complicated by the fact that the resistance of copper changes with temperature, and one ought to take account of this change of resistance because it makes the watts lost increase according to a compound interest law. Moreover, in most cases that arise in practice, part of the heat is radiated from the surface of the coils, and part is conducted along them.

We will first take the case where a conductor is so surrounded by other conductors at the same temperature as itself that the whole of the heat generated in it is conducted to the cooler ends, and none passes to the sides. Afterwards we will take the case where a considerable fraction of the heat passes out to the sides and remainder along the conductor.

Let M be the centre point of a symmetrically situated end connector so surrounded by other conductors that all the heat generated by electric current in it passes to the ends. M is supposed to be the hottest point, and from it heat flows to the right and to the left as

FIG. 8.—End Windings of Two-pole Turbo Field Magnet showing how Coils are bunched together.

indicated by the arrows. It is sufficient to investigate the distribution of temperature on one side, say the right side. Let the distance in centimetres of any point P from M be denoted by x. Let the cross-section of the conductor be 1 sq. cm., so that the volume of any element of length dx is dx cubic centimetre. Now as the resistance of copper is almost proportional to its absolute temperature, the resistance of a centimetre cube may be taken to be—

$$R = \frac{1 \cdot 6 \times 10^{-6} \times T}{273},$$

where T is its temperature in °C. above the absolute zero.

If I is the current density in amperes per square centimetre, the loss per cubic centimetre will be—

$$I^2 R = I^2 \times \frac{1 \cdot 6 \times 10^{-6} \times T}{273}.$$

The amount of heat passing through the centimetre of cross-section at the point P will be the sum of all the heat produced between M and P—that is to say—

$$I^2 \times \frac{1 \cdot 6 \times 10^{-6}}{273} \int_0^x T \, dx.$$

Now the heat conductivity of copper is such that when there is a difference of temperature of 1° C. between opposite sides of a centimetre cube the flow of heat through the centimetre arrear is equivalent to the heat produced by 3 watts. Therefore three times the temperature gradient gives us the heat-flow per square centimetre in watts. As x increases the temperature decreases, so that $\frac{dT}{dx}$ is negative. Thus we have—

$$-3 \frac{dT}{dx} = I^2 \times \frac{1 \cdot 6 \times 10^{-6}}{273} \int_0^x T \, dx.$$

We may take as a solution—

$$T = T_{max.} \cos px.$$

In cases which we work out in practice the angle px never assumes values which make $\cos px$ negative, so that T is always positive. If T were negative it would be below the absolute zero. The above solution would only be wholly true if the resistance of copper were negative below the absolute zero.

The distribution of temperature in a conductor such as we have supposed is therefore given by the top part of a cosine curve as shown in Fig. 9.

The value of p is—

$$\sqrt{I^2 \times \frac{1 \cdot 6 \times 10^{-4}}{3 \times 273}}$$

$$p = 4 \cdot 43 \times 10^{-5} \times I.$$

Therefore—

$$T_x = T_{max.} \cos(4 \cdot 43 \times 10^{-5} \times I \times x),$$

where—

I is the current density in amperes per square centimetre,
x is the distance from the hottest point in centimetres,
T_x is the absolute temperature at any point x,
$T_{max.}$ the absolute temperature at the hottest point.

An example will make this clearer. Suppose that we have a hot-bed of conductors so bulky that we can assume that the centre con-

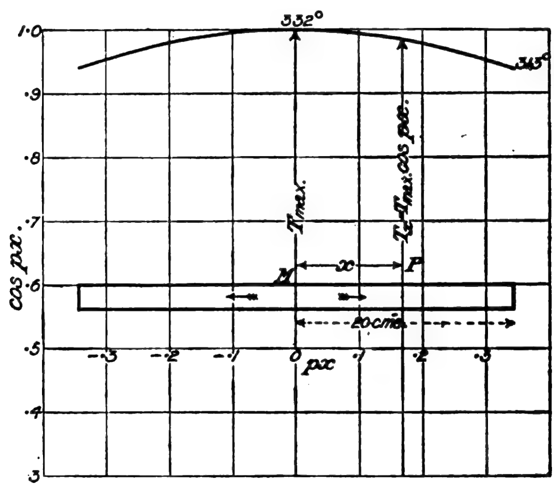


FIG. 9.—Temperature Gradient in a Conductor along which Generated Heat is flowing.

ductor parts with no heat laterally. All heat generated in it passes by conduction to points 20 cm. away from the centre, which we will suppose are maintained at 40° C. Each conductor is 0·1 sq. in. section, and carries a current of 250 amperes. What is the temperature of the hottest point?

$$I = 388 \text{ amperes per square centimetre.}$$
$$T_x = (40 + 273) = 313.$$
$$313 = T_{max.} \cos(4 \cdot 43 \times 10^{-5} \times 388 \times 20).$$
$$313 = T_{max.} \cos 0 \cdot 343 = 0 \cdot 941\, T_{max.}.$$
$$T_{max.} = 332.$$

$332 - 273 = 59°$ C. is the temperature of the hottest point.

Now consider the case where part of the heat generated is radiated from the surface of the group of conductors, and part is conducted to the ends. In all cases which occur in practice there is a certain specified temperature on the outside of groups of coils which must not be exceeded. Assuming in the first instance that the temperature is reached, we can roughly estimate the number of watts per square centimetre which will be dissipated from the surface, having regard to the thickness of insulation and the amount of air circulation. Let W represent the total watts lost in the group of conductors, and w the watts dissipated from the surface. Then $W - w$ will be the heat watts conducted along the copper. The temperature rise of the hottest point will be lower than if no heat were lost laterally. Let us say that the temperature rise is the same as it would be if the current density were reduced from I to I_1 and no heat were lost laterally.

Then—

$$\frac{I_1^2}{I^2} = \frac{W - w}{W}.$$

From the value of I_1 thus obtained we can as a first approximation find the temperature of the hottest point by the foregoing formula, and get a fair idea of the mean temperature of the whole cooling surface. We can then make a more accurate estimate of w, and if necessary recalculate I_1, and from it $T_{max.}$

The experiments which we devised to check the above method of calculation were spoilt by an accident. They are being repeated.

Cooling by Air.

There are three main cases occurring in electrical machinery in which it is necessary to calculate the rate of convection of heat from a solid surface to the surrounding air.

1. We have the case of an armature or field magnet of approximately cylindrical shape revolving within the stationary part of the machine. (Cooling coefficient denoted by h_y.)
2. We have the case of a field coil against which a draught of air is blowing. (Cooling coefficient denoted by h_d.)
3. We have the case of the iron surface of a ventilating duct, through which the air is passing at a certain velocity. (Cooling coefficient denoted by h_v.)

The laws of cooling of the solid surface are different in the three cases. The first case (the cooling of the revolving cylinder) is very complicated. A formula for the close pre-determination of temperatures would have to take into account, not only the square inches per watt and the peripheral speed, but also the length of the air-gap, the temperature and shape of the surrounding objects, as well as of the air, the nature of the cooling surface, and the rate at which the air in the gap is changed by artificial ventilation. What are we to take as the velocity

of the air, relatively to the cylinder, when some air moves with the cylinder, some clings to the stationary part, and all intermediate velocities are to be found somewhere in the air-gap?

For ordinary direct-current armatures surrounded by ordinary field magnets, with normal air-gaps, and with no more interchange of air than is naturally produced by the rotation of the armature, the formula given by Kapp—

$$t^{\circ} = \frac{550}{\frac{O}{W}(1 + 0{\cdot}1\, v)}$$

gives good practical results. Here O is the area of the cylindrical surface in square centimetres, W the watts to be dissipated, v the peripheral velocity in metres per second, and t° the °C. rise above the surrounding air.

Other writers give different values of the numerator 550, and change the value of the coefficient of v. Others change the index of the power of v. Here is a list—

Arnold—

$$t^{\circ} = \frac{300}{\frac{O}{W}(1 + 0{\cdot}1\, v)}.$$

Wilson—

$$t^{\circ} = \frac{640}{\frac{O}{W}(1 + 0{\cdot}18\, v)}.$$

Hawkins and Wallis—

$$t^{\circ} = \frac{412}{\frac{O}{W}(1 + 0{\cdot}086\, v^{1{\cdot}3})}.$$

Ludwig Ott—

$$t^{\circ} = \frac{333}{\frac{O}{W}(1 + 0{\cdot}107\, v)}$$

Hinlein—

$$t^{\circ} = \frac{1{,}730}{\frac{O}{W}(1 + 0{\cdot}78\sqrt{v})} \quad \left\{\begin{array}{l}\text{when } v \text{ is between 1 and} \\ \text{10 metres per second;}\end{array}\right.$$

and—

$$t^{\circ} = \frac{700}{\frac{O}{W}(1 + 0{\cdot}041\, v)} \quad \left\{\begin{array}{l}\text{when } v \text{ is between 10 and} \\ \text{20 metres per second.}\end{array}\right.$$

The reason for the difference of opinion that exists as to the index of the power of v becomes apparent when we examine the results obtained by E. Hinlein* as plotted in Fig. 10. For velocities between

* *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 55, p. 730, 1911.

1 and 10 metres per second h_y is almost proportional to $(1 + 0{\cdot}78 \sqrt{v})$, but as the velocity increases the curve straightens out so that, above 10 metres per second, h_y may be taken as proportional to $(1 + 0{\cdot}041\ v)$. The small coefficient, 0·041 obtained by Hinlein seems to be due to the particular way his experiments were conducted.

For an ordinary armature surrounded by its field magnet the coefficient 0·1 seems to be about right. For the numerator the figure 550 seems to be rather high for iron-clad armatures. The figure 333 given by Dr. Ott seems to give good results for turbo-generators with forced ventilation.

When a cylinder revolves in air, the rate at which the air immediately in contact with it changes depends not only on the peripheral speed but on all sorts of accidental circumstances such as the shape of the stationary parts and the rate at which air is forced into the air-gap by the fanning action of other parts of the machine. A high relative velocity between rotor and stator is of service in causing the heat to pass easily from the heated surface to the air, but some further fanning action is necessary to remove the jacket of hot air away from the surface of the cylinder.

In a certain experiment described below the number of watts of heat-flow communicated to the air by a cylindrical surface of a stator of 2,960 sq. in. was 11,700, so that we had—

$$\frac{11{,}700}{2{,}960} = 3{\cdot}95 \text{ watts per square inch,}$$

or—

$$= 0{\cdot}61 \text{ watt per square centimetre.}$$

The peripheral velocity of the surface of the rotor in this case was 92 metres per second. It was no doubt on account of the high peripheral velocity of the rotor that the cooling on the surface of the stator was so good. The law of cooling of the external surface of the rotor and of the internal surface of the stator will be somewhat similar. It is therefore of interest to apply the formula given by Dr. Ott to the cooling of the surface of the stator. The mean temperature rise of the iron on the cylindrical face appears to have been about 40° C. This is obtained from Fig. 22. The mean temperature of the air in the air-gap was 20·5, leaving a difference of 19·5. Filling in these values in Ott's formula given above, we have—

$$19{\cdot}5 = \text{watts per square centimetre} \times \frac{333}{1 + 0{\cdot}107 \times 92}$$

$$\text{watts per square centimetre} = 0{\cdot}635.$$

This agrees very closely with the actual figure 0·61 obtained.

No doubt the variation of the coefficients has arisen partly through an attempt being made to make the same formula cover the cooling of coils which fall under case 2, as well as the cooling of revolving

cylinders. The cases being essentially different cannot be brought under the same law.

In the case of field coils, an increase in the velocity of the current of air not only increases the intimacy of contact between the air and the surface of the coil, but at the same time increases the quantity of air passing the coil in a given time. We therefore have the index of the power of v greater than for the case of a revolving cylinder, the air surrounding which is not necessarily changed at a rate proportional to v.

In cases 1 and 2 there is a cooling of the surface by radiation, apart altogether from the passage of air, the formulæ should therefore give a value to h when v equals 0.

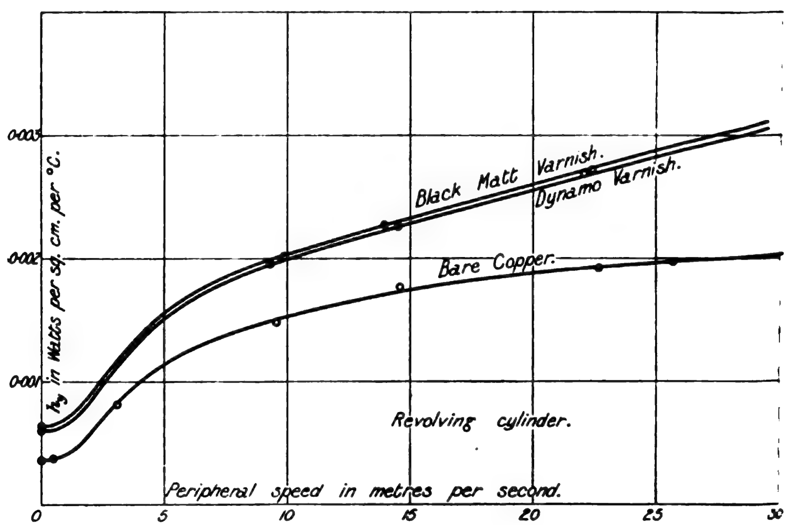


FIG. 10.—Hinlein's Curves for the Cooling of a Revolving Cylinder.

In case 3, where two sides of a ventilating duct face one another, there is no dissipation of heat unless the air moves through the duct, and it will be seen from the experiments described below that the rate of cooling is approximately proportional to v.

For the purpose of determining the relation between the cooling coefficient h_d, in case 2, and the velocity of the draught blowing on the sides of the coil, a number of experiments were made with the apparatus shown in Figs. 3 and 4. A certain number of watts were supplied by the heater inside the coil, and the temperature of the surface of the coil was ascertained by means of thermo-couples mounted in shallow niches in the surface, and protected from the draught by a very thin piece of insulation of a size not large enough to

interfere with the uniform cooling of the coil. Tests were made with no breeze blowing and with breezes of various velocities. The results are plotted in Fig. 11. In these tests the surface of the coil was made up of double cotton-covered wire 0·08 in. diameter. In some other tests a brass cylinder was used. In these the results were much more uniform as shown by the points on Fig. 12. It seems from these tests that the law connecting h_d and v is of the form $h_d = a(1 + bv^2)$, where a and b are constants depending and the kind

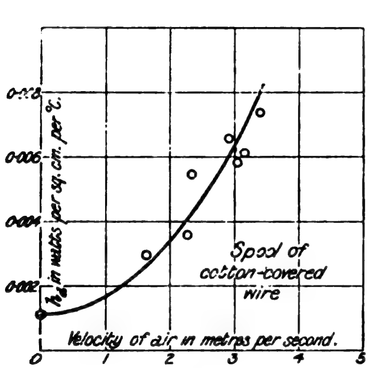


FIG. 11.—Relation between h_d, the Watts per Square Centimetre per °C., and Velocity of Air when Air blows upon a Cylindrical Coil as illustrated in Fig. 3.

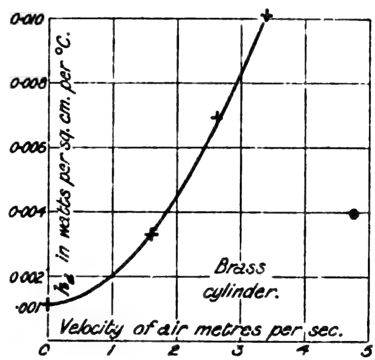


FIG. 12.—Relation between h_d, the Watts per Square Centimetre per °C., and Velocity of Air when Air blows upon a Cylinder of Tarnished Brass as indicated in Fig. 3.

of surface and the way the blast strikes the surface. For the brass cylinder with a draught on each side as indicated in Fig. 3, the law is—

$$h_d = 0·0011\,(1 + 0·78\,v^2).$$

In the case of cotton-covered wire the law is approximately—

$$h_d = 0·0011\,(1 + 0·54\,v^2).$$

In our experiments the draught did not exceed 700 ft. per minute, or 3·5 metres per second. It is possible that at higher velocities the law may change but the velocities investigated cover those generally obtaining in electrical machines.

The third case, the cooling of the sides of a ventilating duct, was investigated in some experiments on a turbo-generator described below. We will give the results here in Fig. 13, because it is of interest to put Figs. 10, 11, 12, and 13 next to one another and observe the difference in the nature of the laws connecting h and v.

In case 3 we know that h_v must be zero when no air passes along the duct, and so far as our experiments go, h_v seems to be almost pro-

portional to v. The dotted line with the two circles on it was obtained by keeping all the conditions constant except that the velocity of the air was changed from 3·95 metres per second to 7·9 metres per second. The other points shown by crosses are from other experiments and calculated for other parts of the machine. Probably the black line may be taken to give the law of h_v for the ventilating ducts for a turbo-generator.

The Cooling of Wire-wound Coils.

In predetermining the temperature rise of a wire-wound coil, we must first find the temperature rise of the external and internal surfaces of the coil. These will be the temperatures at which the coil can dissipate to the surrounding medium all the heat generated within it. In the

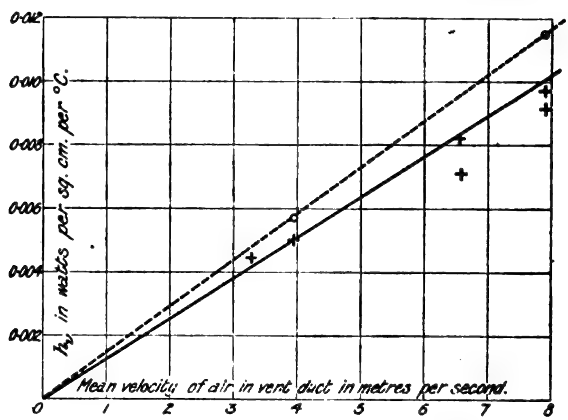


Fig. 13.—Relation between h_v, the Watts per Square Centimetre per ° C. (difference in Temperature between Iron and Air), and the Velocity of Air in the Ventilating Duct.

next place we must find the rise of temperature of the hottest part above the external surface by taking into account the heat conductivity of the layers of insulated wire and the watts per cubic centimetre generated within the coil.

Some designers make their shunt coils to be entirely air cooled. They provide such large air ducts between the coils and the poles that all heat passes to the air. Other designers make the coils a tight fit on the poles, and rely upon conduction of a large portion of the heat generated through the insulation to the body of the pole, whence it passes to the frame, or is dissipated from the pole-face. These two cases require rather different treatment.

Where the coil is entirely air cooled, some rough estimate should be made of the mean velocities of air passing over the external surface and along the ventilating ducts, and from these the specific cooling constants can be arrived at from Fig. 11. Any estimate of this kind will, of

course, be very rough indeed, and it is generally by experiments on similar coils, similarly mounted, that one must rely in determining the surface-cooling constants. Still, Fig. 11 is of service in indicating the direction in which we may hope to obtain an improvement in the cooling conditions, perhaps without much increase in the cost of construction.

Where the coil is a fairly tight fit on the pole, we should take account of the thickness and nature of the insulation and calculate the number of watts which will be conducted to the pole for a given temperature difference in the manner indicated in the example given in conjunction with Fig. 5. The rate at which the heat will be conducted along the pole is sometimes of importance. For this purpose it is useful to remember that a temperature gradient of 1° C. per centimetre in wrought iron causes heat to flow at the rate of 0·7 watt per square centimetre. Account must also be taken of the means that are available for dissipating the heat from the pole itself. For instance, some rotating field generators are provided with vents in the poles, and the laws for their cooling will be somewhat similar to the laws laid down for armatures.

By taking account of these matters and knowing the total watts lost in any particular coil it is not difficult to apportion the loss between the outside, the inside, and the ends of the coil, and come to a fairly accurate estimate of the temperature which the outside surfaces must attain in order to get rid of the heat.

The next question that arises is: How much higher is the temperature inside the coil?

A great deal of most valuable data on the heating of shunt coils is given by Mr. E. H. Rayner in his "Report on Temperature Experiments at the National Physical Laboratory." * A study of the curves and figures given will show that the distribution of temperature inside a wire-wound coil follows definite laws. If we are given full particulars of the size of wire, the thickness of the insulation, the space factor, the number of turns and layers, the exciting current, and so on, we should be able to predetermine with a sufficient degree of accuracy the temperature of the hottest part of the coil.

The problem is somewhat analogous to the case already considered where the heat is conducted along copper conductors, but in this case the heat is conducted across one layer of conductors to another. The law of distribution of temperature takes the same general form—

$$T_x = T_{max.} \cos p_1 x,$$

where $T_{max.}$ is the temperature of the hottest point measured from the absolute zero, and T_x is the temperature of any point distant x centimetres from the hottest point along a line drawn in the direction of the flow of heat at right angles to the cooling surface. The value of $p_1 x$ in practice is such that $\cos p_1 x$ never assumes negative values.

* *Journal of the Institution of Electrical Engineers*, vol. 34, p. 613, 1905; and G. A. Lister, ibid., vol. 38, p. 399, 1907.

If we examine the various curves given by Mr. Rayner we shall see* that they are all part of cosine curves except in those cases where there is a discontinuity in the coil.

Take, for instance, Test No. 2B. Add 273° C. to the ordinates of the transverse section curve on page 639 (vol. 34), and we obtain a curve like that given in Fig. 14. The law of this curve is—

$$T_x = 389 \cos (0{\cdot}0915\,x).$$

If the coefficient (p_1) of x is known, and the distance from the hottest part is known, then we can calculate the amount that the temperature of the hottest part exceeds that of the surface. For instance, with the above law, if on the surface of the winding the temperature is 90° C. (363° absolute) and the hottest point is 4 cm. from the surface, then—

$$363 = T_{max.} \cos 0{\cdot}0915 \times 4$$
$$T_{max.} = 389.$$

The value of p_1 depends mainly on four factors:—

1. The current density in the copper.
2. The nature of the insulation and the thickness per centimetre depth of coil.
3. The space factor of the winding.
4. The ratio of the length of the bobbin to the depth of the winding.

In what follows we shall employ the following symbols:—

l = length of bobbin in centimetres.
d = depth of winding in centimetres.
C_d = current density in amperes per square centimetre.
$C_x = \sqrt{\frac{l}{l+d}}\,C_d.$
σ = copper space factor.
i_n = thickness of insulation per centimetre of depth of winding.
k_k = heat conductivity of insulation in watts per square centimetre per °C. per centimetre of path.

* It is not possible to predetermine the value of p_1 in all the cases given by Mr. Rayner because full particulars are not given of the thickness of the cotton coverings, but in several cases where we may assume the cotton covering is normal and the wires properly packed, the results agree closely, with the values of p found by the authors' experiments; for instance in the case of coil No. 2 we have—

$$p_1 = 127\sqrt{\frac{0{\cdot}63 \times 1{\cdot}6 \times 10^{-6} \times 0{\cdot}136}{0{\cdot}00095 \times 273}} = 0{\cdot}0915.$$

The figures 127 amperes per square centimetre is obtained from the value 151 given in Mr. Rayner's table by the formula for C_x given later in this paper. Length of coil = 7 in., breadth = 3 in.; 7 + 3 = 10.

$$\sqrt{\frac{7}{10}} = 0{\cdot}84\,;\ 151 \times 0{\cdot}84 = 127.$$

Then—

$$p_1 = C_x \sqrt{\frac{1 \cdot 6 \times 10^{-6} \times \sigma \times i_n}{k_h \times 273}}.$$

In order to ascertain the values of k_h for round and for square wire, treated and untreated, the authors made direct experiments on the heat conductivity of cotton-covered wire windings by means of the apparatus shown in Fig. 4.

Experiments were made with two sizes of wire 0·032 in. diameter and 0·114 in. diameter. No current was passed through the wire. The heat was generated inside the copper tube (see Fig. 2), upon which the coil was wound and the temperature difference between two points (a known number of layers apart) ascertained by thermo-couples.

The figures given for the value of k_h in Table III. allow a certain margin for variations in the construction of the coil which, so far as our

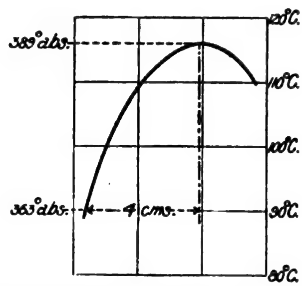


FIG. 14.—Curve No. 2 B from Mr. Rayner's Results showing the Law with Temperatures expressed in ° C. above the Absolute Zero. $T_x = 389 \cos (0 \cdot 0915\, x)$.

tests went, were sufficient for tightly wound coils. For instance, the lowest value obtained for 0·032 in. round wire double cotton-covered electro-enamelled was 0·00065, and the highest value for 0·114 in. wire was 0·0009. It is possible that the margin should be made wider. For loosely wound coils it will be very wide. We assume that k_h is independent of the thickness of the insulation on the wire. The thickness of the insulation of the wire is taken into account in the formula in the quantity i_n, which is obtained by multiplying the number of layers per centimetre with the double thickness of cotton covering on each wire.

Table III. gives the values of k_h.

HEAT PATHS THROUGH THE VENTILATING DUCTS.

After we have provided sufficiently well for the conduction of the heat through the insulation either to the air or to the iron surrounding it, the next question is how to provide sufficient cooling surface so that

TABLE III.

Value of k_h for Wire-wound Coils.

Kind of Wire.	How Treated.	Diameter of Wire.	k_h
		Inches.	Inches.
Square wire double cotton covered	Made solid with electro enamel	0·114	0·00120 to 0·00140
Square wire double cotton covered	Untreated	0·114	0·00090 to 0·00100
Round wire double cotton covered	Impregnated and made into solid block	0·03 to 0·114	0·00085 to 0·00095
Round wire double cotton covered	Treated with enamel	0·03 to 0·114	0·00065 to 0·00090
Round wire double cotton covered	Untreated, tightly wound ...	0·07 to 0·114	0·00050 to 0·00060
Round wire double cotton covered	Untreated, tightly wound ...	0·03 to 0·070	0·00040 to 0·00050
Round wire double cotton covered	Untreated, loosely wound ...	—	0·00020 to 0·00035

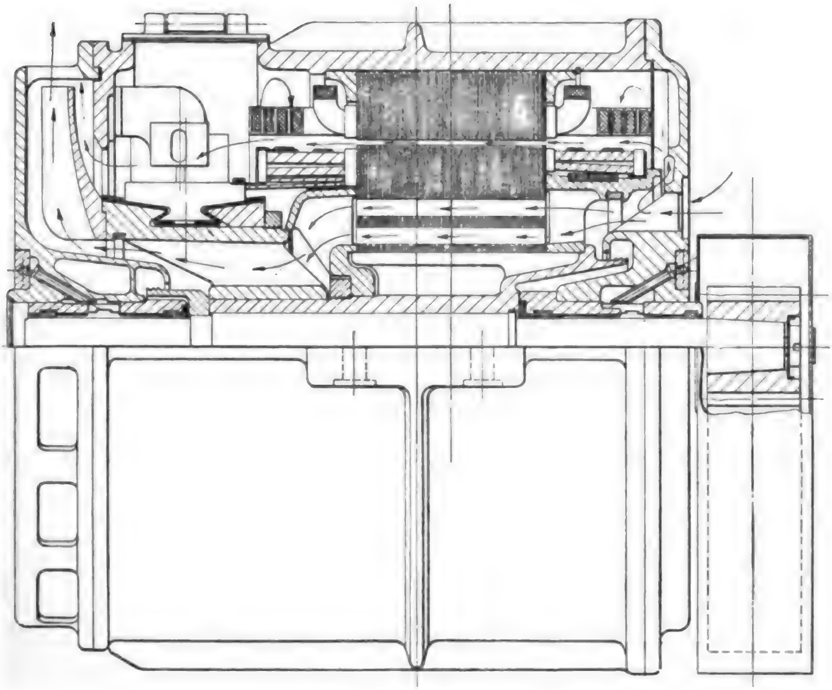


FIG. 15.—Railway Motor with Definite Scheme of Ventilation.

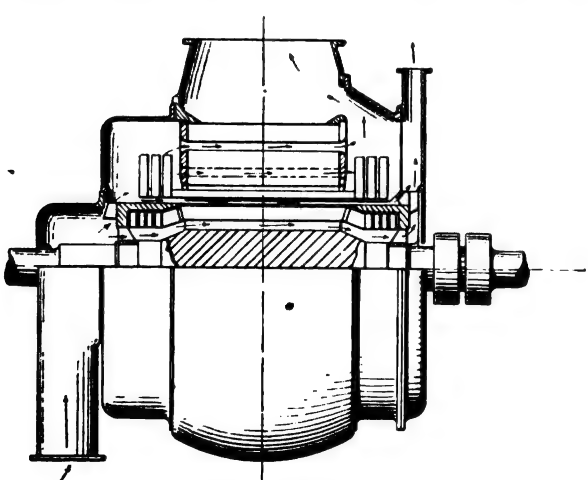


FIG. 16.—Scheme of Ventilation of Turbo-generator by means of Axial Holes; Air passing from one end of Machine to other. (Messrs. Siemens Bros.)

the heat may be communicated to the air and carried away by it. There are really two matters involved; one is the provision of

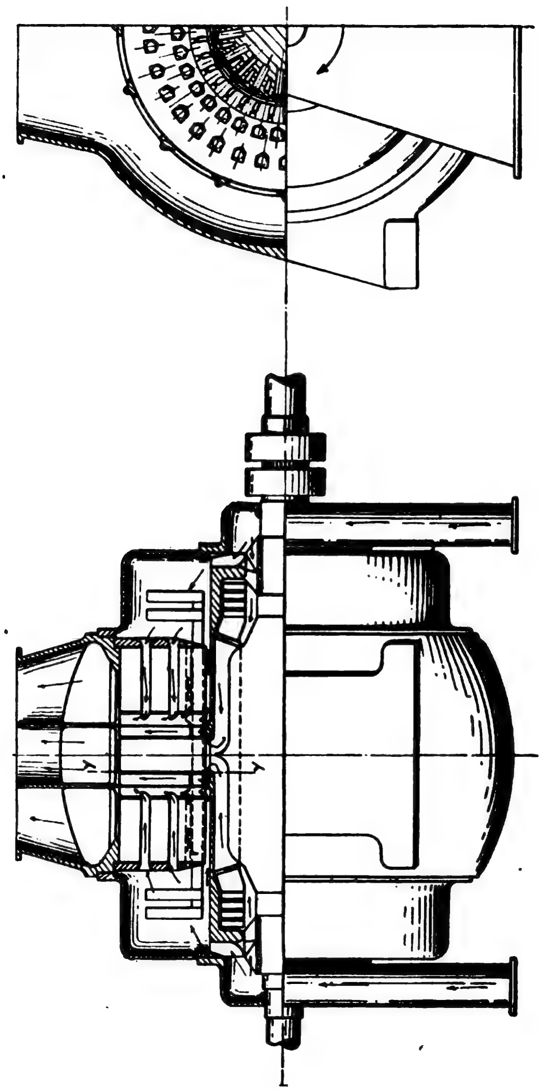


FIG. 17.—Scheme of Ventilation of Turbo-generator by means of Axial Holes; Air passing from both Ends to Middle of Machine. (Messrs. Siemens Bros.)

sufficient air to carry away the heat produced, and the other is the provision of cooling surface exposed in such a way as to heat up the air which passes through the machine.

We know that 1 cub. ft. of air per second (60 cub. ft. of air per minute), if raised in temperature 27° C., will carry away 1 k.w. As a good deal of air sometimes passes through a machine without being raised much in temperature, it is usual to allow 100 cub. ft. of air per minute for each kilowatt loss.

As or how this cooling surface is to be provided is a question upon which there has been a good deal of difference of opinion amongst designers. In the open type of machine where the paths for the air are not very definitely prescribed, and where the quantity of air passing is usually unknown, only the very roughest empirical rules can be used for determining the temperature rise. Where, however, definite paths for the air are provided in the machine as in the motor illustrated in Fig. 15, and where the quantity of air passing is known, the cooling effectiveness of the surfaces can be approximately calculated.

In the cooling of large machines, such as turbo-generators, there are two general methods of providing paths for the air. According to one method, which is illustrated in Figs. 16 and 17, the air is passed through axial holes both in the rotor and in the stator, and it is the internal surface of these axial holes which mainly constitutes the surface exposed. Sometimes the air is passed from both sides of the machine towards the middle, as in Fig. 16, and in other cases the air is passed from one end of the machine to the other as in Figs. 15 and 17.

According to the second method illustrated in Fig. 18, the air is passed through a spider or through axial holes in the rotor, and thrown out through radial ducts in the rotor to radial ducts in the stator.

The first method has been commended on account of the fact that the iron punchings, whose conduction is better along the laminations than across the laminations, can convey the heat more easily to the air than where the ducts are of the radial type parallel to the plane of lamination. How far this consideration is of importance will be considered after we have described the experiments carried out on a machine of the type depicted in Fig. 18. Another advantage of axial ducts is that they provide a more bountiful supply of air to the centre of the machine than is possible in a long machine of the type illustrated in Fig. 18.

The object of the experiments was to determine exactly how the air received its heat as it passed through a turbo-generator and to determine the value of h_v (the watts per square centimetre per °C. difference of temperature between surface and air). At the same time it was sought to determine how far the cooling of the iron was hindered by the poorer conductivity of the punchings across the laminæ than along the laminæ.

As the value of h_v is dependent upon the v, and as it is the velocity of the air in intimate contact with the surface that is of chief importance, we may gather that for a *given quantity of air passed through the machine* narrow ducts will be more effective than wide holes. The ducts, however, must not be too narrow or they will be liable to be stopped

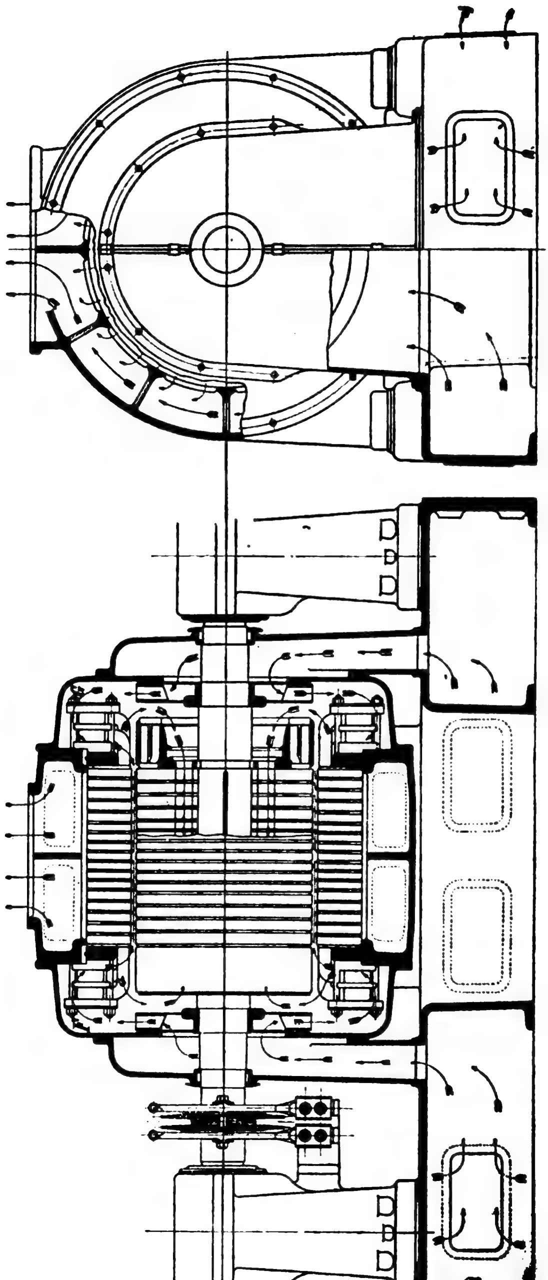


FIG. 18.—Scheme of Ventilation of Turbo-generator in which Cooling Surface is provided mainly by Radial Ducts.

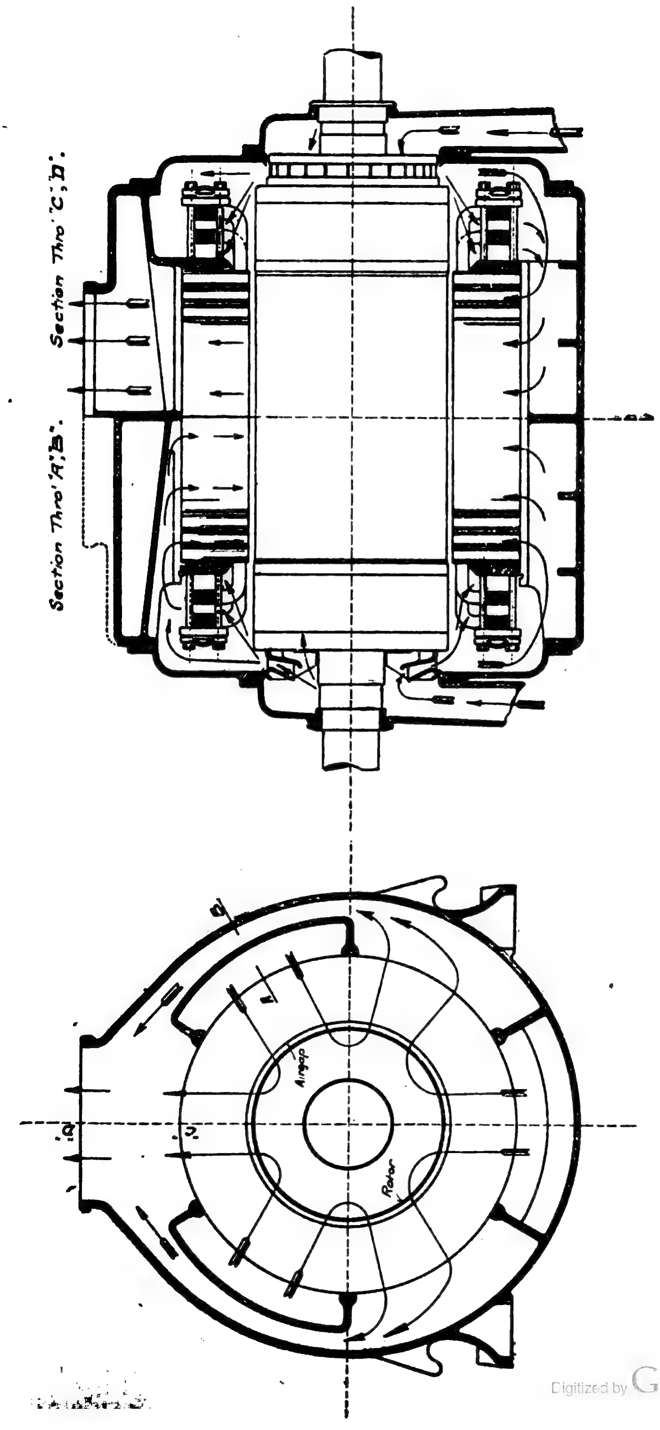


FIG. 18A.—Scheme of Ventilation by means of Radial Ducts into which the Air is fed from various Sectors of the Frame and exhausted into other Sectors. (Brown-Boveri et Cie.)

up by the accumulation of dirt. Holes if too wide allow the air to pass without coming in close contact with the iron. It has been found that ventilating ducts from 0·3 in. to 0·4 in. wide having smooth iron walls will keep clean for a great number of years if the velocity of air passing through them is sufficiently great. A velocity of from 5 to 10 metres per second is sufficient to prevent the accumulation of dust in the absence of oil spray. If any oil is allowed to enter with the air the accumulation of dirt will be facilitated. It has been found that round axial ventilating holes of 2 in. or 3 in. in diameter whose walls are formed from the rough punchings accumulate the dirt very rapidly; this is particularly so with the holes in rotors where the centrifugal

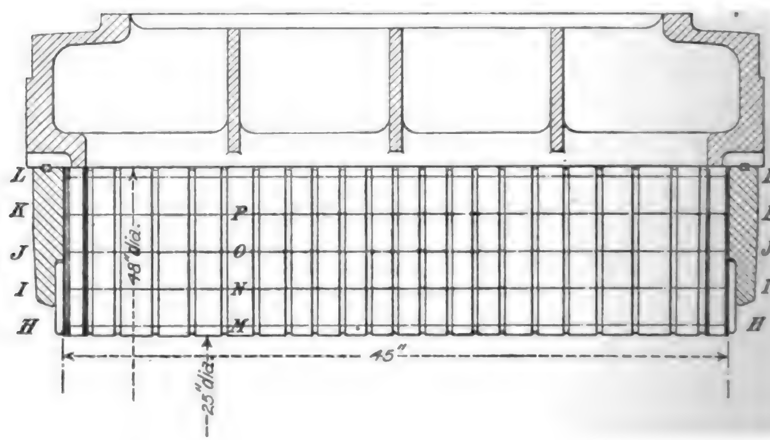


FIG. 19.—Showing Depths H, I, J, K, and L, to which Thermo-couples were inserted into Vent Ducts.

force can press particles of dust together on the internal surface of the hole furthest from the centre.

In cases where one cannot get rid of all the heat from the cylindrical surface of the armature, and where it is therefore necessary to provide further cooling surface, the radial ventilating duct of the type illustrated in Fig. 18 is very effective for the reasons stated above. It enables an exceedingly large surface to be provided without unduly increasing the cost of the machine. It will be seen from the experiments made on the 1,875-k.v.a. generator, as described below, that out of a total iron loss of 43·5 k.w. 11·7 k.w. was conveyed to the air by the cylindrical face of the armature, leaving 31·8 k.w. to be carried away from ventilating ducts and from other exposed surfaces. It is calculated that 23 k.w. of this was communicated to the air by the surface of the ducts and for this no less than 450,000 sq. cm. of cooling surface were required when the difference of temperature between iron and air was 9°. The difficulty of getting a sufficient quantity of air through a

very long machine with a small air-gap can be met by adopting the scheme of ventilation illustrated in Fig. 18A. Here certain channels are provided in the frame from which the air is forced inwards down the ducts to the air-gap and the rotor. Staggered with these channels are others which receive the air thrown outwards from the intervening sectors.

Tests on a 1,875-k.v.a. Generator.

Tests were carried out on a totally enclosed turbo-generator of 1,875-k.v.a. capacity, ventilated in the manner shown in Fig. 18 by means of fans at each end.

In certain parts of the machine ordinarily inaccessible to thermometers, thermo-couples were placed while the machine was in course of construction. Thus in the centre of the packet of punchings lying between the ventilating ducts Nos. 5 and 6 (see Fig. 19) thermo-couples were placed at the points M, N, O, and P. Then in the ventilating ducts at the lower part of the machine couples were exposed to the full blast of air so that readings could be taken of the temperature of the air in the ducts at that part to compare with the temperature of the air in the same ducts at the top of the machine.

The generator was run at no load and the iron loss, friction and windage measured in the ordinary way by measuring the power supplied to the driving motor. The rotor was mounted in its own bearings and coupled to a driving pulley mounted on independent bearings. The pulley was driven by a direct-current motor at 3,000 revs. per minute. The power taken to drive the pulley alone with the full tension on the belt was found to be 13 k.w. The sum of the friction of the generator bearings and the windage was found by deducting 13 k.w. from the whole combination. With full aperture allowed to the fan, the sum of the friction and windage amounted to 46 k.w. In order to ascertain the amount of power lost in the bearings measurements were made of the quantity of oil supplied to each bearing per minute and the rise in temperature of the oil. A rough estimate was also made of the quantity of heat lost by the bearings by radiation and convection. It was found that the heat carried away by the oil in one bearing was equivalent to 7·9 k.w., and from the other 6·7 k.w. The radiation and convection losses of the two bearings together was less than 1 k.w., so the total bearing losses were about 15·6 k.w. This left $46 - 15·6 = 30·4$ k.w. for the windage with full aperture, giving 8,800 cub. ft. of air per minute at 50° C. With a reduced aperture giving 4,400 cub. ft. of air per minute the windage loss was 22·8.

The amount of air passed through the machine per minute was measured in two different ways: (1) An anemometer was used to find the mean velocity of air at the exit in feet per minute, and this multiplied by the area of the exit in square feet gave roughly the cubic feet per minute. (2) The total rise in temperature of the air in passing through the machine was measured, and from the known losses causing

the heating the flow of air could be calculated. The first method was not as accurate as the second. It gave on the average an air velocity from 5 to 7 per cent. too high. We have therefore adopted the figures given by the second method. These are probably right within 5 per cent. It must be remembered that what we are really concerned with is the weight of air passed through the machine per minute. The volume of the air changes with the temperature quite appreciably. Thus at 20° C., 750 lbs. of air have a volume of 10,000 cub. ft., while at 60° C. the volume is 11,400 cub. ft. There were three tests, which we distinguish by the letters A, B, and C.

In test A the air supply was cut down to about half its normal flow. The field magnet was excited with 133 amperes (about 30 per cent. more than the no-load field current.) The resulting iron loss was 43·5 k.w. and the I^2R loss in the field magnet was 8·5 k.w. Thus the total losses going to warm up the air were—

	Kilowatts.
Windage	22·8
Excitation	8·5
Iron loss	43·5
Total	74·8

After running 4 hours the temperature of all the parts of the machine rose within half degree of their final temperature. The air entered the machine at an average temperature of 21·7° C., and was expelled at an average temperature of 53·2° C., giving a temperature rise of 31·5°. The heated air did not represent the whole of the heat produced. The cast iron frame presented a cooling surface of 10,900 sq. in. and had a mean temperature over the air of 28° C., so that it would radiate* in almost still air about—

$$10{,}900 \times 0{\cdot}008 \times 28 = 2{\cdot}44 \text{ k.w.}$$

The cast-iron blocks upon which the frame rested would carry away not more than 1·5 k.w. Let us say that 4 k.w. was lost by the frame. This is such a small fraction of the whole that we need not estimate it very accurately. Then we have 74·8 — 4 = 70·8 k.w. carried away by the air. Now 1 k.w. is equal to 240 calories per second, so we have—

$$70{\cdot}8 \times 240 = 17{,}000 \text{ calories per second.}$$

* It is of interest to note what a small fraction of the total losses on a large turbo-generator are dissipated by external radiation; in this case about 5¼ per cent. In the case of a medium-speed generator of 5 k.w. about 50 per cent. of the losses can be accounted for in external radiation. Radiation is used here in its commonly accepted inaccurate sense and includes convection to nearly still air. The true radiation by heat waves is rather less than half of these figures, and may be calculated approximately from the formula :—

H in gram calories per sec. = surface in sq. cm. of equivalent sphere $\times \sigma \times (T_1^4 - T_2^4)$ where $\sigma = 0{\cdot}6 \times 10^{-12}$ for a dark painted generator and T_1 = temperature of generator in ° C. above absolute zero. T_2 = temperature of surrounding objects above absolute zero.

Taking the specific heat of air at 0·2375 we have—

$$\frac{17{,}000}{0{\cdot}2375} \times \frac{1}{31{\cdot}5} \times \frac{1}{453} \times \frac{60}{1} = 300 \text{ lbs. of air per minute,}$$

or 4,400 cub. ft. of air at 53° C. The anemometer measured on the average 4,800 cub. ft. of air per minute. This reading must be too high, because 4,800 cub. ft. of air per minute raised in temperature 31·5° represents more power than was actually supplied to the machine, so we will take 4,400 cub. ft. as about right.

It is interesting now to see exactly how the air was heated up as it passed through the machine.

The temperature of the air in the various ventilating ducts and in the air-gap was measured by a pair of thermo-couples, mounted on a long wooden rod, which could be moved about in the ducts while the machine was running. Two couples of equal resistance connected in parallel were used, one on each side of the rod, so that if there were any difference between the temperature of the air on one side of the duct and the other, the reading obtained gave the average value. The couples were of such a very thin wire (0·01 in. diameter) and were mounted in such a way that when exposed to a breeze they assumed the temperature of the air almost immediately. It was therefore possible to take very rapidly a large number of readings of the temperatures at different depths in each air-duct, and to plot curves such as those given in Fig. 20. The lines marked H, I, J, K, and L are drawn through the points which give the readings of temperature rise at different depths in the ventilating ducts as indicated by the dotted lines in Fig. 19 bearing the corresponding letters. The hole at the top of the frame at which the air was expelled measured 36 × 20 in., and it was only over this area that it was possible to insert the wooden rod carrying the thermo-couples. In some parts within reach of this hole a flexible strip of press-spahn with a thermo-couple attached was used to take check readings, and the couples placed in the ducts in the lower part of the machine (that is to say, below the rotor) were used as a further check. These lower couples gave readings 2° or 3° higher than couples placed in the same ducts in corresponding positions at the top of the machine. This was possibly on account of the slightly lower velocity of the air thrown downwards, there being a certain amount of back pressure produced by the resistance of the flow of air through the annular space in the frame. As far as could be ascertained by a number of check readings taken over the field, available from the exit hole at the top, the chart in Fig. 20 represents fairly well the distribution of temperature in the ducts in the top half of the machine, and if similar charts had been taken in radial planes at various angles all round the machine, the chart would have been very similar, but all the temperatures would have been gradually raised about 3° as we approached the planes lying below the rotor.

Temperatures were at the same time taken of the air admitted,

of the air in the end bells, in the gap, in the yoke, and at eight different points distributed over the exit.

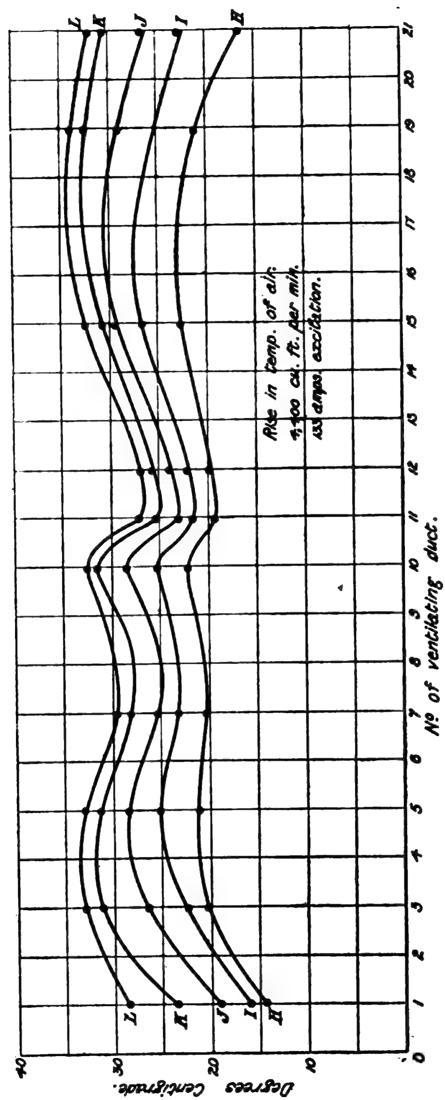


FIG. 20.—Temperature Rise of Air at different Depths in the Ventilating Ducts. Iron loss, 43·5 k.w. Air Supply, 4,400 cub. ft. per Minute.

The average temperature of the air drawn into the machine was 21·7° C. It will be convenient to speak of the temperature rise over

this initial figure, rather than of the actual temperature of the air. In the end bell at the points F and G the temperature had risen 9·8° C. and 10·2° C. respectively. This rise was due partly to the work done to the

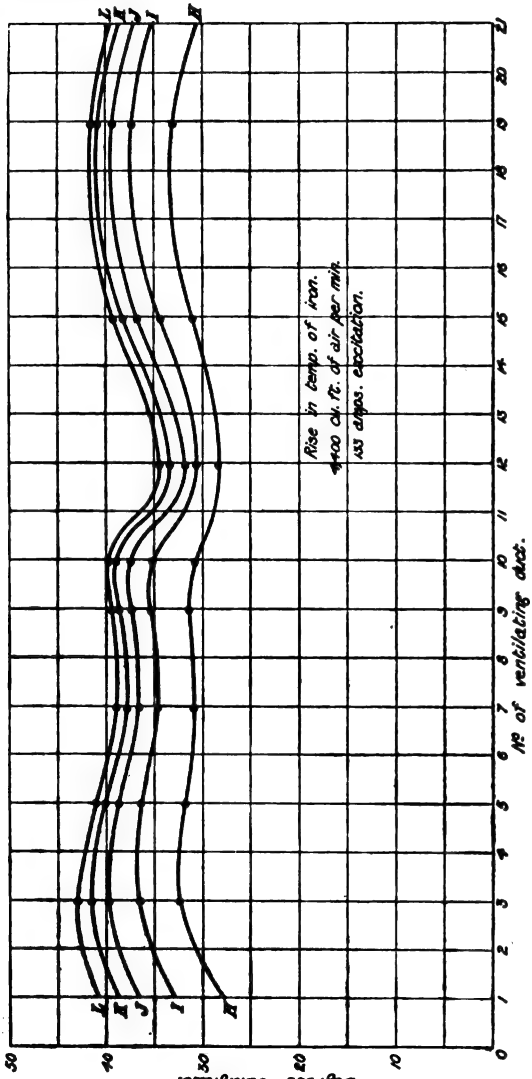


FIG. 21.—Temperature Rise of Surface of Iron in Ventilating Ducts.

air due to the centrifugal blowers, partly windage and I^2R losses from the end bells of the rotor, and partly from heat radiated from end plates of the machine. The lowest temperature recorded in the air-gap was

at the entrance to the first ventilating duct. Here the rise was 14° C. As we passed from the first vent duct to the centre of the machine the temperature was higher, but the increase followed an irregular law as indicated by the wavy line marked position H in Fig. 20. The curious dip in the curve in the centre of the machine which is also seen in the curves of temperature rise in the iron in Fig. 21, only occurred when the air supply was throttled. It does not occur in Figs. 22, 23, 24 and 25. The throttling of the air supply reduced the pressure in the end-bells from 4·25 in. of water for full aperture to 0·75 in. of water. Thus the blast along the air-gap must have been very much reduced, while the blowing action of the vent ducts on the rotor would have taken a more important part in the scheme of ventilation than when the full blast was in operation. Owing to the meeting of the two opposing currents of air in the axial holes in the rotor, there is a tendency for the pressure of air from the rotor to be greatest in the middle, and this increased pressure probably gave a supply of rather cooler air near the centre of the machine.

The velocity of air at the exits of the different vent ducts, though not perfectly constant as one passed from duct to duct, was only very slightly greater in the centre of the machine than at the ends. It is therefore sufficient for our purpose to take the mean temperature rise of the air entering the ducts as derived from curve H at 20·5° C.

Let us now calculate the number of kilowatts, x, required to heat up the air to 20·5° C. We have, from our previous calculations—

$$\frac{x}{70{\cdot}8} = \frac{20{\cdot}5}{31{\cdot}5}$$

$$x = 46 \text{ k.w.}$$

Now the windage only amounted to 22·8 k.w. and the I^2R in the field to 8·5, so that we have 14·7 k.w. in addition which must have been supplied by the iron loss, and communicated to the air mainly on the cylindrical face of the armature. A small amount—probably about 3 k.w.*—would be supplied to the air from the end plates of the armature. Deducting this, we have about 11·7 k.w. conveyed to the air by the cylindrical face of the armature. As we have seen above, we are able from this data to calculate the specific rate of cooling per square inch of armature face.

As the air passes along the vent ducts the temperature rises; in some ducts the air received as much as 11·5° further rise in temperature, in others not more than 8° rise, the mean being about 10·2° rise. If y is the power expended in heating up the air 10·2°, we have—

$$\frac{y}{70{\cdot}8} = \frac{10{\cdot}2}{31{\cdot}5}$$

$$y = 23 \text{ k.w.}$$

* That this amount is small can easily be seen when we come to calculate the amount of heat given to the air in one ventilating duct.

Now the air passes into the annular space in the frame and picks up a little more heat from the punchings. Part of this extra heat is communicated to the frame and is radiated from the outside, and part

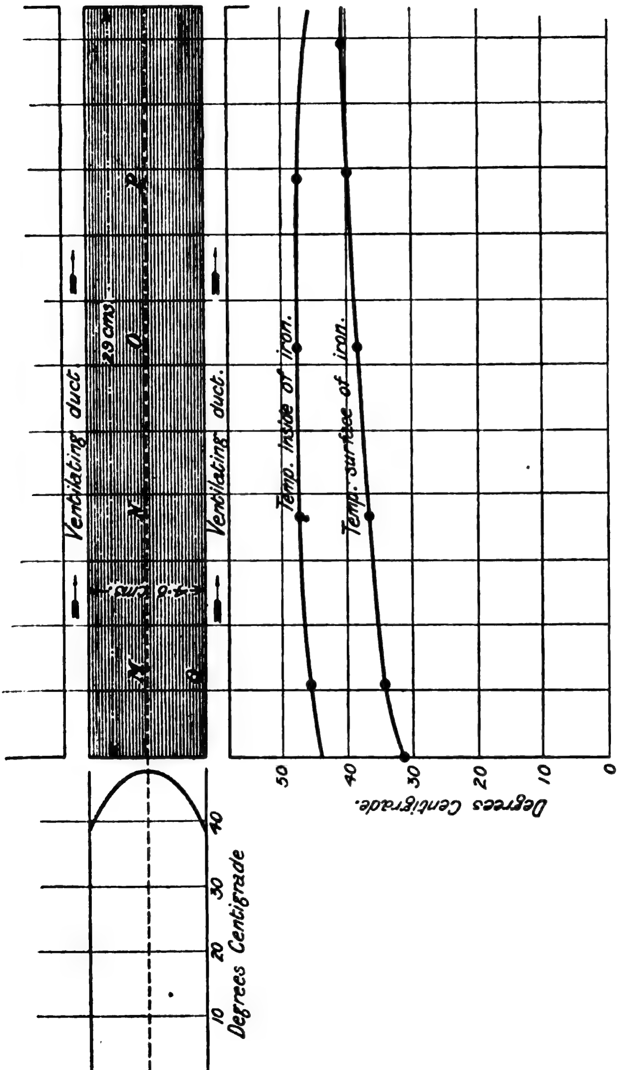


FIG. 22.—Temperature Rise inside one Packet of Iron Punchings 4·6 cm. Thick and 29 cm. Deep. Loss about 0·055 Watts per Cubic Centimetre.

goes to raise the temperature to 53·2° giving a total temperature rise of 31·5°.

The next point of interest is the distribution of temperature in the

iron punchings. The thermo-couples were placed in the centre of a packet of punchings at the points M, N, O, P (see Fig. 22), another couple was placed at Q just behind the first punching in the packet; the packet in question was the one between ducts 5 and 6 in Fig. 19. For the purpose of taking rapid readings of the temperature on the surface of the iron punchings within the ducts an instrument was made which consisted of a piece of copper foil 0·125 × 0·75 × 0·01 in. soldered to a thermo-couple mounted on a velvet cushion, and arranged on a wooden rod so that it could be pushed down the ventilating ducts and pressed against the sheet iron. A spring was provided

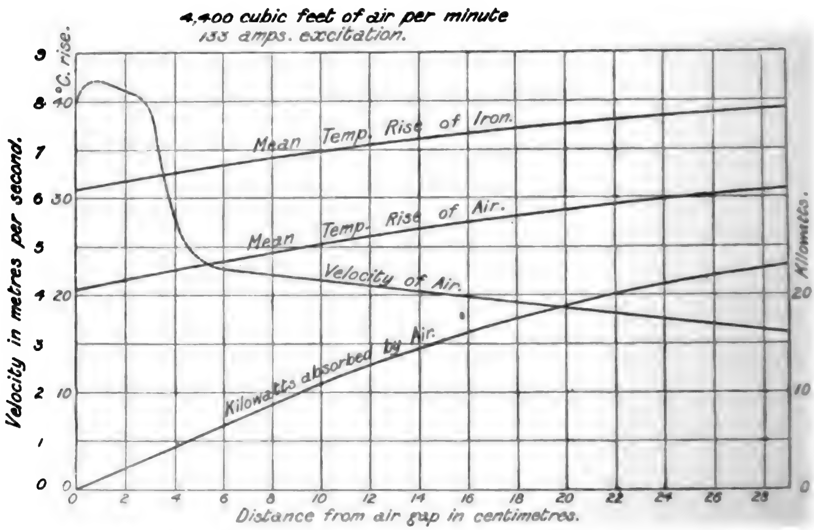


FIG. 23.—Curve showing how the Air is raised in Temperature as it passes along the Ducts and the number of Kilowatts absorbed.

at the back of the cushion to give the requisite pressure, the copper foil being shielded from draughts by the cushion, and being of small heat capacity very soon assumed the temperature of the iron against which it was pressed, thus one could read off directly on a millivoltmeter the temperature of any surface against which the copper foil was placed.

Fig. 21 gives the distribution of temperature of the iron on the surface of the various ducts in test A. The curves H, I, J, K, and L correspond with the positions in the ducts shown by the lines in Fig. 19.

It will be seen that the curves follow the general shape of the curves giving the rise of temperature of the air, but they are on the whole about 10·5° higher for the position H and 8·5° for the position L.

If we take the average value of the temperature of the air at the position H, then the average value at the position I, and so on, and plot these average values, we get a curve giving the mean temperature rise of the air as it passes through the ventilating ducts, like that shown in Fig. 23. The ordinates in this figure give the rise above the tem-

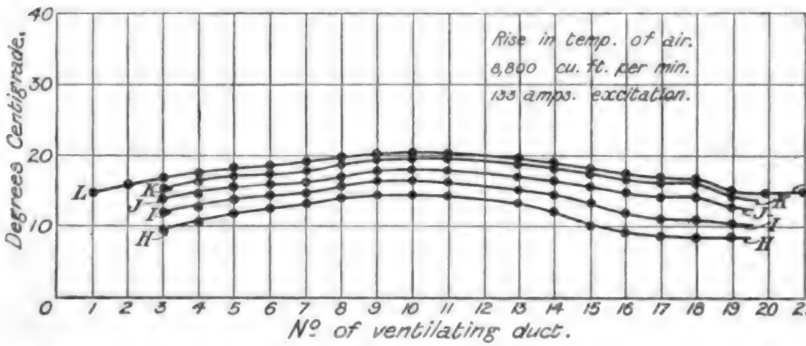


FIG. 24.—Rise in Temperature of Air with Air Supply doubled and Losses as before.

perature at which the air enters the machine, the rise before reaching the ducts being 20·5°, and the rise in the ducts being 10·2° C.

Taking similarly average values of the temperature of the iron at the various positions, we get a curve of temperature rise of the surface of the iron.

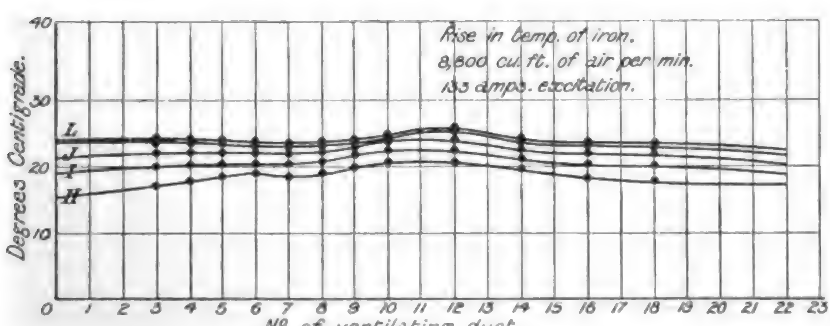


FIG. 25.—Rise in Temperature of Iron with Air Supply doubled and Losses as before.

As the total amount of air passing though the ventilating ducts was 300 lbs. per minute, it is possible to calculate the watts absorbed by the air from the rise in temperature by the formula—

$$\text{Kilowatt} = \frac{300 \times 453 \times 0{\cdot}2375 \times \text{temperature rise}}{60 \times 240}.$$

Plotting the kilowatts absorbed by the air, we get the curve shown in Fig. 23. The velocity of the air in that part of the ventilating duct which was narrowed by the armature coils was 8·4 metres per second, in the part of the ventilating duct beyond the armature coils the velocity was 4·5 metres per second, and at the exit of the ventilating ducts the velocity fell to 3·2 metres per second. Plotting these figures we get

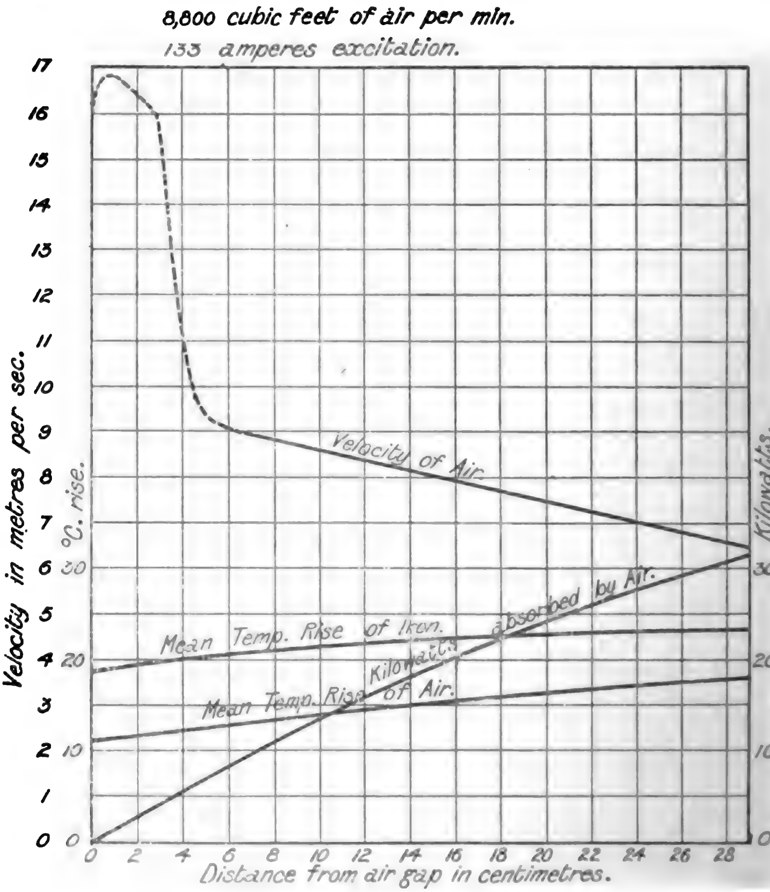


FIG. 26.

the velocity curve in Fig. 23. We have given on the same figure the difference of temperature between the iron surface and the air, the velocity of the air and the watts absorbed. If we take the slope of the curve giving the watts absorbed, say at a point 16 cm. from the entrance to the duct, the slope of this line gives us the kilowatts absorbed by the air per centimetre travel. At the point of the 16 cm.

the rate is 800 watts per centimetre. The temperature difference between the air and the iron at this point is 9°, and the total area of the ventilating ducts to which the air is exposed in traversing the centimetre length of path is—

$$(300 \times 2 \times 21) + (72 \times 2 \times 21) = 15{,}600 \text{ sq. cm.}$$

If we denote by h the watts per square centimetre of cooling surface per °C. difference of temperature between surface and air, we have—

$$h = \frac{800}{9 \times 15{,}600} = 0{\cdot}0057.$$

This is at an air velocity of 3·95 metres per second.

In order to see the effect on the distribution of temperature throughout the machine with a greater draught, in test B the air supply was increased to 8,800 cub. ft. per minute, the iron loss and excitation

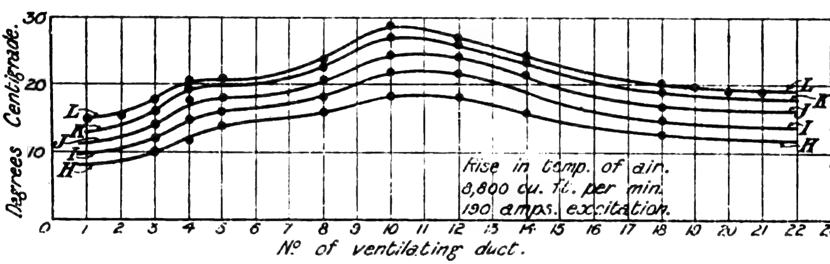


FIG. 27.—Rise in Temperature of Air Supply doubled and Iron Loss increased to 56 k.w.

losses being as before. The temperature of the air in various ducts is given in Fig. 24, and the temperature of the various parts of the surface of the ducts in Fig. 25. Plotting the average values of the air temperatures at different depths in the ducts, we get the curve marked "Temperature rise of air" (Fig. 26), and plotting the average values of the surface temperatures of the iron, we get the curve marked "°C. rise of iron" (Fig. 26). On this figure is also plotted the velocity of the air as it passes along the ducts and the kilowatts absorbed by the air. Taking the tangent of the watts absorbed at the point 16 cm. from the internal cylindrical face of the stator, we find that the air is picking up heat at the rate of 1,250 watts per centimetre length of path. The difference of temperature between iron and air at this point is 7° C., and the total area of surface exposed for 1 cm. of path is 15,600 sq. cm. as before; we therefore have—

$$h = \frac{1{,}250}{7 \times 1{,}5600} = 0{\cdot}01146,$$

the velocity of the air being 7·9 metres per second. We see from

these experiments therefore that h (the watts per square centimetre of cooling surface per °C. difference of temperature between surface and air) is almost exactly proportional to the velocity of the air. h, in fact, is given by the equation—

$$h = 0{\cdot}00145\,v,$$

where v is the velocity of the air in the ventilation duct in metres per second (see Fig. 13).

In test C the air supply was maintained at 8,800 ft. per minute, but the iron loss was increased to 56 k.w. and the excitation losses to 17·5 k.w. Under these conditions the temperature distribution of the air and iron in the ducts is given by Figs. 27 and 28 respectively. The

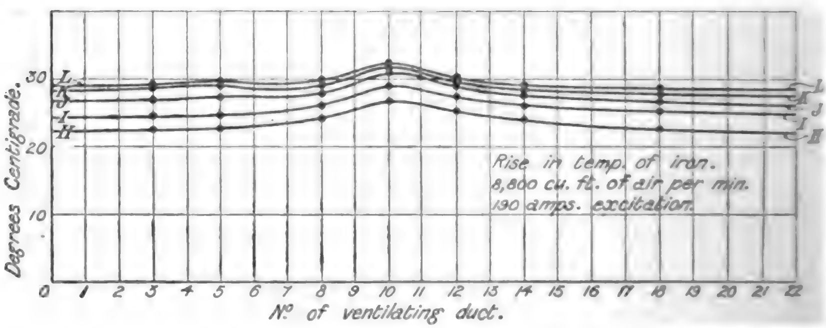


FIG. 28.—Rise in Temperature of Iron with Air Supply doubled and Iron Loss increased to 56 k.w.

mean temperature rises of air and iron at different depths in the duct are given in Fig. 29. The watts absorbed by the air at different depths are also given on this Fig. 29.

CONDUCTIVITY OF IRON PUNCHINGS.

If we have a packet of iron punchings in which the loss per cubic centimetre is constant, and if all the heat generated is conducted across the packet and given off symmetrically to the air in the ventilating ducts which bound it on each side, the hottest part of the punchings will be in the centre, and the temperature gradient at any point within the iron will be proportional to x, the distance of the point from the centre. Let w be the watts lost per cubic centimetre, then $w\,d\,x$ will be the loss in a little part of the iron laminations 1 sq. cm. in area and $d\,x$ cm. thick. The total heat generated in a block 1 cm. high and 1 cm. wide, and of length x will be $w\,x$. If K_h is the heat conductivity in watts per square centimetre per °C. difference of temperature per centimetre, the temperature gradient

$\frac{d\theta}{dx}$ multiplied by the heat conductivity is equal to wx. As $\frac{d\theta}{dx}$ is negative when x is positive we—

$$-K_h \frac{d\theta}{dx} = wx.$$

$$\theta = \text{constant} - \frac{w}{2K_h} x^2.$$

The curve of temperature distribution within the iron is therefore a parabola such as that plotted in Fig. 22.

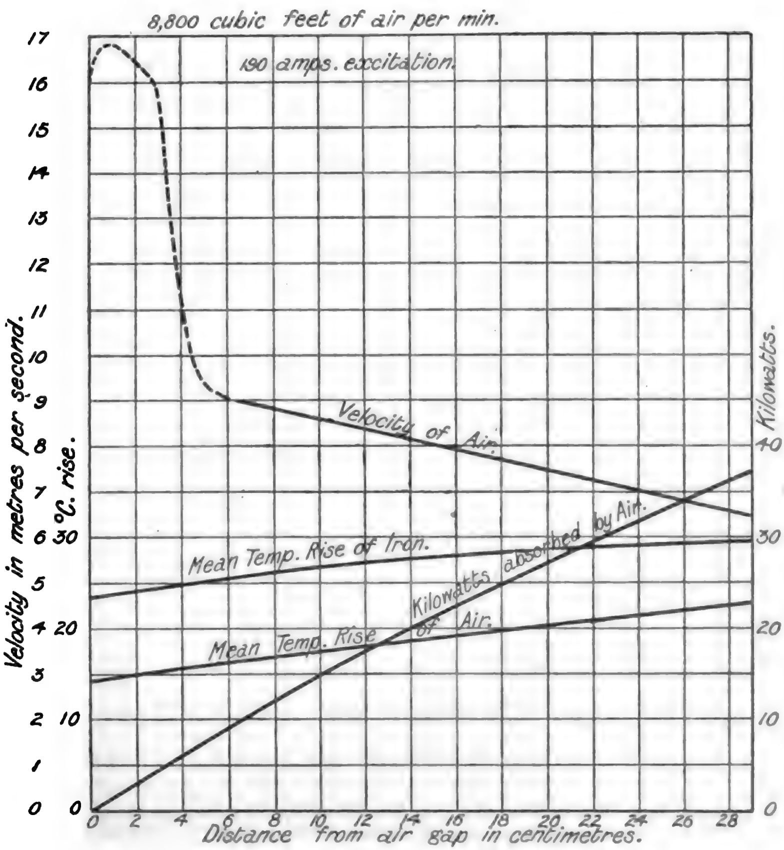


FIG. 29.

In the experiments above described measurements were made of the temperature in the centre of the packet and on the exterior. Knowing the loss per cubic centimetre of iron we can calculate K_h as follows :—

The total iron loss amounted to 43·5 k.w. Of this 4·5 k.w. was in the teeth, and 39 k.w. behind the teeth. The total volume of iron behind the teeth was 710,000 cub. cm.

Thus—

$$\frac{39{,}000}{710{,}000} = 0{\cdot}055 \text{ watt per cubic centimetre} = w.$$

It is seen from Fig. 22 that the temperatures on the medial line between P and N were almost constant for points on both sides of O, so that the amount of heat conducted from O towards P and N would not be very great. It would not be negligible because the conductivity of the punchings in this direction is so much greater than the conductivity across the laminations. Let us take the figures at the point O, where the heat conducted along the laminations is at a minimum, and calculate the conductivity on the assumption that all the heat flows to the walls of the ventilating ducts.

Now there are 8° difference of temperature between the centre and the surface of the packet, so we have—

$$38 = 46 - \frac{0{\cdot}055}{2\,K_h} x^2 \text{ (see Fig. 22).}$$

$$8 = \frac{0{\cdot}055}{2\,K_h} (2{\cdot}25)^2.$$

$K_h = 0{\cdot}0174$ watts per square centimetre per ° C. per centimetre.

$K_q = 0{\cdot}0042$ caloric per second per square centimetre per ° C. per centimetre.

The formula given by Dr. Ott for the heat conductivity across laminations is—

$$K_q = \frac{\delta_1 + \delta_2}{\frac{\delta_1}{K_1} + \frac{\delta_2}{K_2} + \frac{1}{a}},$$

where—

δ_1 = thickness of iron in centimetre.

δ_2 = thickness of insulation in centimetre.

K_1 = conductivity of iron = 0·15.

K_2 = conductivity of insulation (paper = 0·0003) (varnish = 0·0006).

a = conductivity of rough surface. This may be between 0·5 for smooth and 0·04 for very rough iron.

In our experiments $\delta_1 = 0{\cdot}041$, $\delta_2 = 0{\cdot}0033$, the insulation being paper. The formula gives $K_q = 0{\cdot}0035$.

In the experiments described the loss per cubic centimetre, 0·055 watt, was rather high. This was because the machine was run at 30 per cent. above its normal field excitation. A more usual figure for 50 cycles would be 0·045 watt per cubic centimetre. If then we take the conductivity of the punchings at 0·0174 watt per square

centimetre per ° C. per centimetre we have θ, the difference in temperature between the surface and middle of the packet—

$$= \frac{0{\cdot}045}{2 \times 0{\cdot}0174} x^2.$$

For a packet 4·5 cm. thick ($x = 2{\cdot}25$) the excess of temperature would be 6·5° C. and the mean temperature of the iron above the surface only 4·5° C.

At 25 cycles the loss per cubic centimetre would be about 0·025 watt per cubic centimetre. Here the packets might be about 6 cm. thick for the same temperature rise in the hottest part.

In any case, it is seen that unless the packets are made much thicker than is usual in practice the temperature rise in the centre due to the poor heat conductivity across the laminations is not of very great importance.

Conclusions.

We see, then, that in arranging for the cooling of large electrical machines the following matters must be taken into account :—

1. Sufficient air must be provided to carry away the heat generated. If 100 cub. ft. of air per minute is provided for each kilowatt loss it will in general be sufficient. If the conductivity for heating of all parts is sufficiently good and the air is so distributed that none of it receives a temperature rise greater than 32° C. it may be that 60 cub. ft. of air per minute would be sufficient to keep the machine below 45° C. rise.

2. Sufficient cooling surface must be provided to communicate the heat to the air.

3. For ventilating ducts we may take the formula—

$$h_v = 0{\cdot}0014\, v.$$

Where h_v is the watts per square centimetre of cooling surface per ° C. the difference of temperature between surface and air and v is the mean velocity of the air in the duct in metres per second.

4. For the cooling of the surface of rotors and the internal cylindrical face of stators we may take the formula—

$$t^o = \frac{333 \times \text{watts per sq. cm.}}{(1 + 0{\cdot}1\, v)}$$

5. To find the difference of temperature between an armature coil and the surrounding iron one can adopt the method given on page 682, using the constants for the heat conductivity of the insulated material given in Table II., and allowing for air-spaces whose resistance is given roughly by Fig. 5.

6. To find the temperature rise of the surface of wire-wound coils upon which the air is blowing with a velocity of v metres per second we may take the formula—

$$h_a = 0{\cdot}0011\,(1 + 0{\cdot}54\, v^2).$$

7. To find the difference between the inside of a wire-wound coil and the external surface we may follow the method given on page 695.

8. To find the difference between the temperature of the centre and the cooler parts of a hot-bed of conductors cooled mainly by the conduction of the heat along the conductors we must adopt the method given on page 686.

In conclusion, we wish to express our indebtedness to Mr. H. M. Evans and Mr. R. D. Hobden for their diligence in conducting some of the most tedious parts of the investigations, and to Mr. S. G. Nottage for the work he has done in plotting the results. We also wish to express our thanks to the British Westinghouse Company for the facilities they have given us in carrying out the experiments and for their permission to publish the results.

Discussion.

Mr. Law. Mr. A. H. Law: The points which the authors have brought forward must be of the very greatest interest to every designer. Table II., I think, is particularly interesting, although a certain amount of the ground has been covered before by work done elsewhere. Perhaps the most interesting thing is the relatively small difference between the results in column 10. I think if any of us had not these results before us we should have been inclined to say that the difference in the thermal conductivity of different insulating materials would have been greater than this. The lowest and the highest figures are both for mica compounds. The lowest figure contains 19 per cent. of shellac, and the highest figure is practically pure mica, so that probably for ordinary commercial working we can take a figure about half-way between the two, which brings the figure for mica very much in line with the figures for other materials. In the same way with regard to the varnished empire cloth, which is the next highest figure, probably in actual practice it would not be possible to press it as tightly as has been done in this experiment, and consequently perhaps that figure would be slightly reduced. As a result it appears that the difference in the thermal conductivity of different insulating materials if used intelligently is not very great. I was very much interested in the various methods of ventilation described and illustrated in the figures, particularly in Fig. 18, which I understand is the same type of machine as that on which all the experiments were made in the later part of the paper. I have used this system of ventilation in a number of large machines almost identical with that shown in Fig. 18, that is, in plants up to 6,000 k.w., in the larger alternators using a screw fan in place of a centrifugal fan. The question of fans on large alternators is certainly rather a vexed one, owing to the difficulty of getting high efficiencies for the fans. As far as I can make out in the experiments done on the 1875 kilovolt-ampere plant of the authors, the efficiency of the fan with a small quantity of air was in the neighbourhood of 2¼ per cent., and of the

fan with the large quantity of air it was about 19 per cent. I do not want the authors to think that I am giving these figures as being exceptionally bad ones. I know myself that with a fan of this type on a revolving field magnet a figure of 19 per cent. is nearly as high as it is possible to get. Of course the figure of 2¼ per cent. was obtained with the fan doing a great deal less than its proper duty. Considering these efficiencies further, we find that if in place of these fans an external fan of a really efficient type had been used, an amount of from 16 to 20 k.w. might have been saved in the losses in this machine. This amount would be, I suppose, about 20 to 25 per cent. of the total losses, and consequently it is conceivable that in this way the rating of the plant might have been increased by 10 per cent. I do not think this applies to small plants, as it is obviously inconvenient to use separately driven fans on a plant of moderate size; but for very large machines I think the separately driven fan with its high efficiency is undoubtedly the proper solution of the ventilating question. The authors mention in dealing with the question of the thermal conductivity of the laminations that the conductivity along the laminations is one hundred times as much as it is across the laminations, and they pointed out the small relative importance of this difference. There I very much agree with the authors. The alternative to passing the heat across the laminations is to carry the air through longitudinal ducts in the core, but this means that the bulk of the ventilating air is never compelled to pass over the surface of the rotor coils or the stator coils, and therefore the stator coils at any rate can only be cooled by conduction through the iron. In Fig. 18 an arrangement is shown in which the whole of the ventilating air is pumped into the rotor, and first passes over the surface of the rotor coils, which it is well known are the limiting factor for the output of a turbo-alternator; then it passes over the surface of the stator coils, which, being usually of high tension, should be kept as cool as possible; and finally passes through the air ducts, and cools the stator iron, which relatively is of lesser importance. Thus we get the greatest cooling in the rotor copper; next to that we get the best cooling in the stator copper; and finally we deal with the heat in the iron. I was very much interested in Fig. 20 and the following figures, showing the dip of temperature in the centre of the stator core. The authors give an explanation for this on page 708, where they say it is due to the relatively greater importance of the fanning action of the rotor when the air was throttled. I have observed the same thing, and in some cases to a very considerably greater degree, in a large number of machines. I do not think it is entirely due to the cause assigned by the authors, and I think that from their own figures it can be proved that the iron losses at the centre of the stator—that is to say, in the bundles of laminations near the centre of the stator—are less than in the bundles of laminations near the end. Compare Figs. 27 and 28, in which the stator is being worked with a large amount of air passing, and with what is, I take it, more than the normal iron loss of the machine. In Fig. 27 it will be noticed that the air supply at the centre of the stator is very much hotter than it is

Mr. Law.

Mr. Law. at the ends, whereas the actual temperature of the iron given in Fig. 28 is only very slightly above what it is at the ends; it follows that the difference in temperature between the cooling air and the iron at the centre is less than the difference in temperature between the cooling air and the iron at the ends. As a result it follows that the quantity of heat passing from the iron to the air is less at the centre than at the ends, since the author tells us on page 708 that the quantity of air at the centre was only very slightly greater than at the ends. I am not sure whether I have made myself quite clear as to this, but clearly if the air is coming out at the same temperature as the iron, no heat is passed from the iron to the air. If the air is coming out only one or two degrees cooler than the iron, then only a small amount of heat is passing from the iron to the air, and at the centre of the stator the difference is comparatively small, whereas at the ends the difference is considerable. This, it seems to me, shows that the iron loss in the centre is lower than it is at the ends, although the air is actually hotter owing to its having picked up heat while passing along the rotor ducts and air-gap. It would be an easy matter definitely to make a test of this by stopping up the ventilation of the plant altogether, and running for perhaps 10 or 20 minutes, and then measuring the temperature rises. No heat will have been carried off in the air, and the actual temperature rise of the iron would be a measure of the loss. I shall take the first opportunity of making that experiment. In the machines in which I have been concerned there is an easy explanation for the loss being greater at the ends, and that is that the shaft which projects from the rotor core reduces the saturation in the portions of the rotor near the ends. I take it that the authors' rotor is built up of discs of steel mounted on a shaft, and if therefore, as is undoubtedly the case in Figs. 27 and 28, where the machine is running above the normal voltage, there is a considerable amount of saturation, it seems likely that the saturation will be less at the ends than it is at the centre, and as a result the flux density in the stator iron near the ends of the machine will be greater than at the centre, and consequently the losses will be higher.

Mr. Rayner. Mr. E. H. Rayner: It is very pleasant to find one's work of some years ago useful to present-day designers, as the authors have mentioned in two or three places in the paper. The design of turbo machines is not in my line at all, but there are many ideas in connection with the work carried out which are extremely useful; and if the authors had not done this work, or if they had passed the ideas on to me, I should have been pleased to have carried out some of the laboratory work on these lines. But still I had not the idea and they had. With regard to the remarks of Mr. Law, I do not think I can in any way claim that any of the thermal conductivity results as given in Table II. depend on my work; they all, I think, depend on that of the authors. They mention at the bottom of page 679 that the heat conductivity of empire cloth at a temperature of 100° was considerably greater than at atmospheric temperatures. I presume the authors tested this at, say, normal temperatures of 40° or

50° C.; then allowed it to heat up, and tested again at the higher temperatures. Did they then test again at the lower temperatures, because I think they would very likely have found an improved conductivity at the lower temperatures on account of the materials sticking together? This would considerably improve the conductivity, and the 10 per cent. or 12 per cent. mentioned might be accounted for in that way. On page 702, and on the following pages, the question of cooling through ducts is taken into account. As a result of experiments on other lines, I am told that if air is sent through a heated tube the temperature of the outgoing air is very largely independent of the velocity. If the velocity of the air be doubled, the temperature still keeps up, and if it be doubled again the temperature still keeps up; in other words, the air does not seem to go through the tube solid, with the middle of the stream cooler than the outside. It is all very effective in cooling, however, so that for a very large range of velocity we can still depend on the air being useful for cooling purposes. There is no reduction in the temperature of the air as the velocity is increased, as one would be inclined to think. On page 705 some very interesting figures are given—I have no doubt that their importance is realised by designers—as to the actual amount of air required to cool a machine which is not a very large one—under 2,000 k.w. in size. It works out at 300 lbs. of air per minute, which is a very considerable amount when put into cubic feet. Air has the advantage of being very cheap and of being able to travel at a great velocity, but its density is so small that it requires an enormous volume and a correspondingly large cross-sectional area of cooling ducts in the machine in order to get this amount through. It seems to me that if instead of air we could use water for cooling, instead of getting through 300 lbs. per minute, which works out, I think, at 2,000 odd litres of air per second, a little more than half a litre of water would have the same cooling effect. It seems to me that if it were possible to cool the stator of the machine by means of water tubes the volume of liquid required would be of the order of 3,500 times less. In that way a small quantity and a small cross-sectional area of pipes would be very much more efficient than the air that is at present required. May I venture to supply a few somewhat wild ideas for the authors' criticism? I will take the general question of the cooling of large machines—how it is done at present and how it is possible to do it. First of all we have air cooling, which, I suppose, is quite general, and the value of velocity I have already mentioned. I have already suggested that water cooling in tubes might possibly to some extent replace air cooling with considerable advantage if it were practicable. It might also be possible to do it in the rotor. Then there is a third system of cooling of a large generator, which I am afraid is impracticable although it sounds very nice, namely, to treat it as we should a high-voltage transformer and immerse it completely in oil. That is not possible on account of the great peripheral speed of the rotor, but I think it might be possible to immerse the stator in oil. An oil-tight shield would be wanted around the inside of the stator, Mr. Rayner.

Mr Rayner. which should have no eddy currents in it, but otherwise it would be possible practically to immerse the stator in oil and pump cooling oil through it. Then there is also another possible principle theoretically, and that is to make the conductors in the high-voltage windings in the form of tubes, and either pump water or oil through them and cool them in that way. The hole would want more cross-section in the middle of the conductor than designers would be inclined to allow, but it is possibly a practicable method. Water could be pumped in at the centre of the earthed star system, and be allowed to drop out at the high-voltage ends of the conductors. There is no trouble in doing that; it is the ordinary method that is used in all Swiss power stations for making lightning arresters by means of a little jet of water. If water is objected to, oil could be used; but I am afraid the viscosity of the oil would be rather high and the specific heat is considerably lower. Half a pint of water per second, if we could get it, would be extremely valuable through the internal conductors of the high-tension windings. There is another point on which I am quite convinced the authors have made a great discovery, although perhaps they do not know it. In discussing this paper with some authorities on aerodynamics, I gave them the figure for the calibration error of the anemometer. The authors say that the two sides of their equation balance within 10 per cent.—in other words that the anemometer error was not above 10 per cent. That seems to be an extraordinarily good anemometer. I was asked whether Mr. Miles Walker had ever had it calibrated to get it so near as that. The authors have invented a method of calibrating anemometers of which they may not be aware, and which would be especially useful at low velocities. Taking a stream of air (flowing in a pipe) whose velocity is required, we can put into it by electric heating a measured amount of energy per second. If also the corresponding increase in temperature is measured, it needs but a knowledge of the specific heat of air at constant pressure to calculate the velocity. The electrical and thermometric measurements would give no trouble; and since the authors give the specific heat even to four figures, an accuracy of about 1 per cent. might well be expected.

Mr. Everest. Mr. A. R. EVEREST: Referring to the heat-jacketing effect of the insulation, the figures given by the authors differ quite considerably from other figures that have been obtained from testing in many cases, and it may be of interest to refer to the other tests in order to compare them. The first tests made several years ago consisted in taking a large alternator coil insulated with tape and varnish to a depth of $\frac{3}{16}$ in. and passing a current through it so as to heat it; the change of resistance was used to determine the internal temperature whilst the outside was measured by a thermometer. The figure deduced from that test gave a constant of about 230° C. rise for 1 watt per square inch in an inch thickness. Another test made in a calorimeter on a coil insulated in the same way with tape and varnish gave very similar results—about 236° C. Later there were a number of tests made on different kinds of insulation, tested between plates, and the figures

Mr. Everest.

obtained from those tests for varnished cloth and other similar materials came out very much the same—in the neighbourhood of 240° C. Also about the same time a test was made with a composite insulation containing 30 per cent. mica, and that gave 400° C. for 1 watt per square inch on an inch thickness. A very careful test was made some three years ago with a view to getting more exact facts, and I refer to this particularly because it has several points of similarity to the authors' tests. Wooden cylinders were used in this case about 15 in. long and 2 in. in diameter. Each cylinder was first of all wound with a layer of fine insulated wire, which served as the heating coil and also as the measure of the temperature. Outside that was the layer of insulation to be tested, and outside again another layer of fine wire, whose resistance was measured periodically. From the changes of resistance of the two coils the internal and external temperatures were plotted. Those tests as regards impregnated fibrous materials gave about 240° C. rise for 1 watt per square inch across an inch thickness. In view of those various tests and others which have been made it is a little difficult to understand the figure which is given in the paper, which, expressed in the same terms, comes out in the case of the first item, varnished cloth, at 158°, which is only a little more than half. Several of the other fibrous materials in this table give results which are just about what would be expected from the tests referred to. I do not know whether the authors can suggest anything that will throw more light on that subject. Then as regards mica, undoubtedly pure mica has a very high heat conductivity, and the authors have shown us tests on three pieces of mica $\frac{1}{16}$ in. thick which gave a constant of 110° C. for 1 watt per square inch across an inch thickness, which is extremely low. But unfortunately we cannot use pure mica on coils in that thickness, but mica put into wrappings must be in the form of thin laminæ. From the authors' figures as well as the other tests mentioned, it can be seen that when mica is present in a composite insulation the resistance to heat-flow is increased. In the eighth item in Table II., which refers to the actual coil insulations described by the authors and illustrated on page 683, the observed result is given in several terms, but in the terms I have used it comes out at 350°, which is somewhat high. In connection with that I would like to ask if there is not an error in the figure given on page 683, where the description is given of this winding in the slot. The statement is made that "the difference of temperature between the copper and iron is 20·6° C.; mean perimeter 6·8 in.," and the constants for heating are deduced apparently from that figure. But the dimensions as given do not give that at all; they give 5·3 in., which makes quite a difference in the constant. There is also another point on which I would like to ask the authors if they can throw some more light. In the core as shown on page 683 and in the results given, the difference of temperature between the internal copper and the iron was about 21° C., which is about what I think would have been expected. But at the coil ends the difference between the inside and outside is only about 16°. Is that due to there having been less insula-

Mr. Everest.

tion on the coil ends, or is it due to the fact that eddy currents were present in the slot portions which were not present in the end portions? I think it would be interesting to have that point explained more fully. There is one other thing I should like to refer to, namely, the cooling constant in still air which is referred to on page 681. Possibly I have misread the figures, but apparently the constant is given as 0·0011 in watts, although sometimes calories are used. That works out to 360° C. rise for 1 watt per square inch surface. In a large number of tests made at different times the value has always come out somewhere in the neighbourhood of 100 to 110° C. There is one other comparatively minor point to which attention might be called. In connection with heat conductivity along the copper conductors the authors take the absolute zero of resistance at — 273° C. Now the absolute zero of resistance, or the equivalent zero of resistance as given by the American Institute Standard Rules, for some time past has been — 238°. I see that in the new revised rules issued a few months ago they now make it — 234°. It makes a slight correction in the direction of bringing down the temperature of drop along the conductor as calculated in the paper, and I mention it particularly because the figures given in the example calculated seem to me to be somewhat high as compared with the figures that would be derived from more familiar methods.

Mr. Sack.

Mr. T. J. SACK: I desire in the first place to draw attention to Table II. As Mr. Law has already pointed out the relative positions of the materials, so far as their thermal conductivity is concerned, I will not go over that matter again. But there is one interesting point worth noticing, namely, that the thermal conductivity is almost proportional to the disruptive strength. If we take mica, which is first in order of thermal conductivity, that has a disruptive strength of anything up to 3,000 volts per mil. The second on the list, empire cloth, has a disruptive strength of 900 to 1,000 volts per mil.; the third, empire cloth and mica, when of equal proportions, 50 per cent. of cloth and 50 per cent. of mica, has a disruptive strength according to my tests of 875 volts per mil., and so on. I do not think the proportion of mica to cloth materially affects the result. The value of the figures given is somewhat discounted by the fact that the amount of air-space has such a great effect on the results. It is very noticeable that the results which come out rather higher than we should expect are those obtained by Bacon's method, in which it is possible to eliminate the air-spaces to a greater extent. I refer to the result obtained for press-spahn, which seems rather high, and to that of pure mica, which is extraordinarily high. I think those high results are due chiefly to the method which was adopted. I was rather astonished to find that the micanite tube, consisting as it should do of nearly all mica, gave such a poor result. Going carefully into the matter I found that the percentage of shellac that the authors have shown for their tubes is rather high. A good machine-wound pure micanite tube should not have more than 5 per cent. of shellac in it. There is one other point regarding machine-wound tubes to which I wish to refer, namely, that they are wound

under very heavy pressure, which tends to eliminate all air-spaces; so that I believe a much higher result, and nearer to the result obtained for mica, would have been obtained had the tube been machine-wound. I think the high result obtained with empire cloth is also due to the fact that it can be wound much tighter, and air-spaces thus eliminated. It is rather interesting to note that in America empire cloth has come very much into vogue for cable insulation. One of the points that are urged for it is that a cable insulated with empire cloth is better able to withstand an overload, or, in other words, an increase in temperature. I believe the fact that the cloth possesses this property of having a high heat conductivity accounts for this result, the heat being conducted away quicker. I was rather disappointed to find that the authors have not shown any results for leatheroid, vulcanised-fibre and paper as used in cables, as these materials are in very extensive use nowadays, and the results would have been very valuable. Touching on the question of air-spaces, it seems to me a most vital thing to eliminate all air-spaces in the slot of an armature. Messrs. Fleming and Johnson proved conclusively that chemical action can be almost entirely eliminated if the air-spaces are eliminated.* Further, the puncture voltage is increased if all the air-spaces are eliminated; and the authors have told us, and proved by their figures, that the thermal conductivity is thereby improved. Mr. Sack.

Mr. S. E. GLENDENNING: I think we want to know more about the permissible velocities of air, the size of fans and air-passages necessary, etc. One hears of makers who keep five or six different sizes of fans in stock, and try them on the machines during test until they get the desired result. The question of water-cooled machines raised in the discussion is not quite a new one. My firm has quoted on water-cooled motors, and has pointed out to the customer that he could use the ordinary domestic water service, but users are prejudiced against water and seem to prefer air. One point in connection with the arrangement of ventilating passages, with which the authors are no doubt fully acquainted, was not mentioned in the paper. A turbo-generator is apt to act as a sort of mechanical air-filter. If the air is turned quickly round a corner one seems to get the same effect as in a steam separator. The heavy particles (of dust in this case) carry on, while the air turns round the corner, and an accumulation of dust is the result. This, as well as the actual cooling effect, ought to be taken into consideration in designing air-passages. The authors rightly mention the effect of roughnesses in the air-passages in collecting dust—another very important point. If I might make one complaint in connection with this paper, it is that I wish the authors would keep to one series of units. When we get centimetres and inches mixed up it makes things rather involved; and I have not yet had time to translate all the authors' very useful formulæ into square inches and degrees Fahrenheit, in which I usually work. Mr. Glendenning.

* *Proceedings of the Institution of Electrical Engineers*, vol. 47, p. 530, 1911.

Professor Thornton.

Professor W. M. THORNTON (*communicated*): In such a series of researches as the authors' the variables can only be dealt with in turn but in practice each part is affected by the changes going on elsewhere. It would be an advantage if examples could be given of temperatures calculated from the new results and of observed values on load. An aggregation factor might thus be found by which, for given types, the temperature of any part could be predetermined on load from tests on it alone. With reference to the heating of magnet coils, it has been shown by Mr. G. T. Williams,* from prolonged experiments on small machines running *in vacuo* that very nearly one-half of the heat liberated in the field coils is removed by convection, the remainder by radiation and conduction. One-quarter of the total field heat is removed by the fanning action of the rotating armature in the case of a 7-H.P. Westinghouse direct-current motor. The authors find a smaller proportion with large enclosed machines. The question of flow of heat in armatures is complicated by inequality in its rate of production. Both eddy currents and hysteresis loss, in so far as they depend upon flux density and its variation, are much greater in the active belt at the circumference than deeper in the core. For a given quantity of heat liberated the armature might be expected to run somewhat cooler than predicted by experiments where there is uniform heating, on account of the more ready escape of heat from the outer parts; on the other hand, for a given mean heating, the temperature would be higher at the circumference.

Mr. Taylor.

Mr. H. W. TAYLOR (*communicated*): At the present stage in the development of electrical machinery a scientific understanding of the heat distribution and "heat paths" is essential, and the importance of the subject has probably been appreciated by designers in two stages. First, the vigorous circulation of air in quickly revolving machinery of the present day enables more heat to be expelled from a given size of structure; secondly, when advantage is taken of this fact, larger temperature drops result from carrying larger quantities of heat from the source of generation to the place of radiation, thus giving rise to "hot spots." The experiments described in the paper upon the heat conductivity of insulations are interesting in this respect, and as applied to high-voltage machines one is sometimes prompted to ask whether there is not an economical limit to the stator voltage for a machine of given output. Generally speaking, a high-voltage machine (11,000 volts and above) should work with a lower temperature-rise under maximum conditions than a low-voltage machine, because of the heat drop across the coil insulation. The stator core density must therefore be lower in proportion. Again, in a high-voltage machine there is more insulation and probably much more copper, so that the active belt is wider. All these considerations point to a larger and therefore more expensive machine—so much so that there are probably cases in which it is more economical to generate at half voltage and step up to full voltage in auto-transformers.

* *Electrician*, vol. 63, p. 706, 1909.

Mr. Taylor.

In view of the divergence of practice at the present time in high-speed construction and especially in methods of ventilation, as discussed by the authors on page 699, and as evidenced by various figures in the paper, it is interesting to speculate as to whether one type of machine will be evolved from the variety of designs now manufactured by different makers, in the same way that the present universal type of slow-speed machine has been evolved from the several different types which existed in the eighties and nineties. The ventilation of the rotor should receive foremost attention for the following reason. With a given diameter a compromise must be made in the rotor design between the space to be occupied by windings and the remaining space which is to carry flux, and with the diameter restricted by mechanical considerations it follows that the highest rating at a given speed is obtained in that rotor which is most perfectly ventilated. It seems desirable, therefore, to give the freest access of air to the rotor. This is probably best effected by means of frequent radial ducts along its length, similar to Fig. 18, the air being propelled by vigorous fans and the rotor being ventilated from both ends. The rotor itself is probably the most effective fan in this respect, but additional impellers may be mounted on the shaft. Care, however, has to be exercised in the design of these latter to ensure that they are capable of delivering the total amount of air required into the intermediate space between them and the rotor cavities at an increase in the air pressure, otherwise they will form merely an obstruction. The air leaving the rotor cavities will pass into the air-gap, and although it will be raised in temperature somewhat by friction between the stator and the rotor surfaces, it is probable that a large amount of heat is here extracted from both the stator and rotor punchings. The partially heated air will subsequently pass from the gap region into the ducts provided in the stator punchings, as with frequent rotor ducts, as suggested, this would seem to be the only means of passing off the rotor air. The stator will not be so cool as it would be if it were provided with fresh cool air, but there is no consideration except that of cost which limits the loss in this part of the machine. It is admitted that with this system of ventilation higher windage losses result than in such constructions as that shown in Figs. 16 and 17, but on the other hand, much better ventilation is obtained, so that for a given output the percentage friction loss may not be widely different, and the method described has the advantage from the point of view of highest output for a given limit in mechanical construction. As regards the ventilation of the end windings, it would seem most desirable, in view of the above considerations regarding rotor heating, to provide separately propelled air streams for these regions, discharging these into the region at the back of the punchings. It may, however, be desirable to provide discharges quite separate from those for the air from the punchings, owing to the fact that with two fans arranged to discharge into the same passage a slight difference in pressure between the two discharges will reverse the flow in the less powerful one.

Mr. Roberts. Mr. R. J. ROBERTS (*communicated*): In glancing over the separated losses of a turbo-generator it is very soon noticed how great a proportion the air friction loss is to the whole. Not only does this air friction increase the lost energy of the turbine, but it also adds to the heat generated, and this must be carried away by a larger quantity of air. With radial ventilating ducts in the core it is scarcely possible to reduce the air friction, because the air must flow through them, and the friction loss is approximately proportional to the quantity of air multiplied by the square of the rotor peripheral speed. With axial ducts so much air friction is not obtained. In a test of a 500-k.w. turbo-generator with radial vents it was found that the air friction alone was sufficient to raise the temperature of the ventilating air 20° F. If axial vents had been used with a separately-driven fan this air friction might have been very greatly reduced and a gain in temperature-rise effected, say 12° F.—this would have been well worth considering. I quite recognise the objections to axial ducts, such as dirt deposition, but still I think that, for some such conditions as turbo-generators with a peripheral speed above, say, 90 metres per second, the axial ventilating duct is superior to the radial.

DISCUSSION BEFORE THE MANCHESTER LOCAL SECTION ON 12TH DECEMBER, 1911.

Dr. Rosenberg. Dr. E. ROSENBERG: The authors have given much valuable information in a compact form. Some papers which have treated a small part of the questions dealt with here have given the results of their investigations in such cumbersome form that they are not handy for use. If a designer would try to figure out a temperature-rise of a new machine with such formulæ, it would take him weeks and months before his calculations were finished, and another designer might, in the same time, have the machine already designed, constructed, and tested—perhaps even rejected, and built another one which conforms to specification. All these heating formulæ, whether they are empirical or theoretical, must needs neglect a lot of factors, and therefore represent in the best of cases only an approximation, and to be useful such formulæ must be simple and short, as indeed are all the formulæ given in this paper. This paper deals with a question which is most important for the designer and for the life of the machine, because it shows the internal temperature-rise, which ordinarily is never measured, and of which the customer and the consulting engineer in general have no knowledge. It is entirely a question between the designer and his own conscience. As far as the usual specifications go a machine passes the test if the temperature-rise of no accessible part exceeds 40° C., but we see from this paper that it is quite possible that in one machine the highest temperature of a non-accessible part may be only 20° above the measured temperature, while in another machine 60° may be the difference between the hottest and the measured parts. In the absence of this knowledge, electrical engineers have chosen the same rule that

Dr. Rosenberg.

mechanical engineers choose when they do not know the forces coming on to a structure: they have allowed what is called "a high factor of safety." We know from experiments that untreated cotton is not carbonised when subjected continuously to a temperature of 125° C. Paper and mica, of course, can stand much higher temperatures. With a room temperature of 25° C. the limit for the temperature-rise would therefore be 100° C., and if we specify 40° C. measurable temperature-rise on full load, this would be a safety factor of 2½ (corresponding to a mechanical safety factor of 2½ for the elastic limit), allowing a margin of 60° C. for the unknown internal temperature-differences and for overloads. If we knew the internal temperature-differences we could specify a greater temperature-rise, and at the same time be safer than now, just as a mechanical structure might be safer in which all forces occurring are well known, and only a safety factor for the elastic limit of 2 allowed, than another construction in which important forces are neglected, and for the forces taken into consideration a safety factor of 5 is allowed. If we consider that with a given machine the internal temperature-differences are in a certain relation to the measured temperature-rise and not to the measured temperature, we also see that it is wrong to specify the same ultimate measured temperatures for different external room temperatures. If, for instance, say for India or Persia, the room temperature is considered as 40° C. and a temperature-rise of only 25° C. is specified, the ratio of the available temperature-rise (up to 125° C.) to the specified measured temperature-rise is $85/25 = 3{\cdot}4$, and if somebody would allow for a cool climate with 0° C. room temperature 65° C. measured temperature-rise, his safety factor would dwindle down to $125/65 = 1{\cdot}9$. To keep the safety factor in all cases the same, namely, 2·5, we should allow in the first case 34° C. and in the second 50° C. measured temperature-rise. One of the most interesting theoretical parts of the paper is the calculation of the hottest spot in a coil in which the heat travels only in one linear direction (pages 685 and 686). The formula—

$$T_x = T_{max.} \cos (4{\cdot}43 \times 10^{-5} \times I \times x)$$

is perhaps misleading if it is thought that $T_{max.}$ can be regarded as a constant. In reality T_x can be considered as a constant, because it is possible to keep the temperature of a certain measurable point ($x = x_1$) at a certain value, and then we find that the greatest internal temperature-rise over this measured temperature can be represented as—

$$T_{max.} - T_x = T_x \cdot \frac{1 - \cos (4{\cdot}43 \, . \, 10^{-5} \, . \, I \, . \, x)}{\cos (4{\cdot}43 \, . \, 10^{-5} \, . \, I \, . \, x)};$$

and this formula shows that for a given current density I there is always a certain finite length x, which will make the denominator zero, and therefore the value of the fraction infinite. In the sample of the authors, for instance, it is only necessary to take the length, instead of 20 centimetres, as 91½ centimetres to get to this point. The existence

Dr. Rosenberg.

of such a critical point, however, although strange at first sight, is explained by the fact that the specific resistance of copper is proportional to its absolute temperature, and it is clear that if the temperature-rise with constant resistance under the given assumptions were 273° C., and the resistance really is doubled due to this temperature-rise, that this again would double the temperature-rise and double again till infinity is reached. I would mention that the formula is only correct under the assumption that the heat conductivity is constant for variable temperature. From the figures available in good hand-books, I find that for a copper cube of 1 metre each side, the heat transmitted for 1° C. temperature-difference is 320,000 gramme calories per hour, which would correspond to 3·7 watts heat flow for a cubic centimetre. The authors' figure is 3 watts.

The authors have shown how detrimental air-pockets are from the heating point of view, and we know how detrimental they are from the insulation point of view.* This shows the great value of thorough impregnation. The experiment of the authors which shows the value of the radial air-ducts is of great practical importance. Some engineers were completely misled in this question by experiments referred to in this paper which showed that the heat conductivity of a sheet-iron packet is approximately 80 or 100 times as great in the direction of the sheet as compared with the direction across the sheet. The practical conclusion is not by any means that air-ducts parallel to the sheet are without value, but only that the distance of air-ducts parallel to the sheet must be smaller than the distance of air-ducts across the sheet in order to allow the same internal temperature-rise inside the packet. This question has also been theoretically dealt with by Ossana.†

Professor Marchant.

Professor E. W. MARCHANT: With regard to heat conductivities, the best given in the paper for insulation is 0·009 for pure mica. I had the curiosity to look up some figures in Everett's book of "Physical Constants," and find that the figure for copper on the same basis is 4·2, so that we get a ratio of heat conductivity between mica and copper of about 400. I should like to make one criticism with regard to the experiments that were made on the heating of coils. I notice that in the interior of this coil solder was used to conduct the heat from the heating coil to the copper surface which was in contact with the insulating material. I would like to suggest that mercury would have been better for that purpose, since its heat conductivity is more than twice as good as tin. There is one point which is not dealt with in the paper, *i.e.*, the rate at which the armature or field coil heats up. I worked out only a few days ago a rather interesting result which may possibly be of some value. The temperature-rise of a coil supplied with a constant amount of power and in which the heat loss is assumed to be proportional to the temperature-rise is given by the formula $\theta = \theta_f\,(1 - \varepsilon^{-t/\tau})$; where θ is the temperature-rise at time t, θ_f is the

* Fleming and Johnson, *Journal of the Institution of Electrical Engineers*, vol. 47, p. 530, 1911.

† *Elektrotechnik und Maschinenbau*, vol. 27, p. 489, 1909.

final temperature-rise, and T is a quantity usually called the heating time constant, and depends on the mass and specific heat of the coil and on the radiating surface. The value of T may be found approximately, for a transformer or other similar machine, by observing the rate of decrease of temperature of the coils per degree of temperature-rise. The heating time constant is the reciprocal of this quantity. In order to estimate it, the transformer may be run for a short time, the power supply to it shut off, but all cooling arrangemements left working, and the rate of decrease of temperature observed. To take an example: In a given case the temperature rise of a transformer was 20° C. The power supply was cut off, and the machine allowed to cool. The temperature fell 2° C. in ten minutes. The time constant = 1/rate of cooling per ° C. = 100 minutes. This estimate is of course approximate only, but serves to show for how long the heat run should be continued. Theoretically, the temperature-rise at the end of a time equal to the heating time constant will be 63·6 per cent. of the final rise. At the end of a time three times as great as the heating time constant, this temperature rise will be 95 per cent. of the final rise, and this time for heat run is ample for all practical purposes. Professor Marchant.

Mr. J. S. PECK: When engineers first began to make electrical machines, they built them first and rated them afterwards. But as the laws of the magnetic circuit became better known, and as the quality of iron and steel reached some degree of constancy, machines could be designed with some degree of certainty, at least in so far as efficiency was concerned; but the question of predetermining the temperature-rise in a new machine has been, and is still, a most difficult one. Differences of 50 per cent. in the temperature-rise from the calculated values are not uncommon, and in most cases temperature-rise of a new machine is predicted from previous tests on similar machines rather than from calculations on heat conductivity and radiation. The authors' paper marks a distinct advance, in that it brings us one step nearer to that position when in the design of electrical machinery empirical rules may be replaced by exact mathematical formulæ. Mr. Peck.

Mr. J. K. CATTERSON-SMITH: I should like to draw attention to a few results I have obtained which refer to the empirical temperature formula given on page 717 of the authors' paper. In section 4 they give an expression of the form originally introduced by Dr. Hopkinson for the final temperature-rise of the surface of an armature, and which I understand has been checked by Mr. Miles Walker for turbos at 92 metres per second peripheral velocity. Now I do not think it is permissible to use this expression, as it stands for other types of machines and very different values of velocity, for, as is well known and stated in the paper, the cooling depends greatly upon the design of the structure for ventilation, and I think this is the explanation of the difference in the various expressions on page 718. I give below a number of coefficients for this form of expression which I have taken from test figures, and it will be noticed that there is a considerable divergence Mr. Catterson-Smith.

Mr. Catterson-Smith.

from the figures quoted in the paper. I would like to say with regard to the armature surface O (page 718) that it is most important to specify whether this is the total cylindrical surface of the armature or the smaller cylindrical surface of the core only. In the equations below, the total armature loss, W, on load includes the stray losses due to armature reaction effects; O is the cylindrical surface of the armature ($= \pi \times D \times L$, where L is the overall barrel length), v is the peripheral velocity in metres per second, taken up to 25 to 30 metres per second. For armatures of ordinary open type, multipolar construction up to about 2 feet in diameter—

(a)
$$t^\circ \text{C.} = \frac{350}{\frac{O}{W}\left(1 + 0.22\,v\right)},$$

(b) If the loss is referred to the core surface only, then—

$$t^\circ \text{C.} = \frac{700}{\frac{O}{W}\left(1 + v\right)};$$

for large machines in which the cooling is much more effective—

(c)
$$t^\circ \text{C.} = \frac{300}{\frac{O}{W}\left(1 + 0.20\,v\right)}.$$

From these equations it will be seen that a considerably higher rating of an armature is obtained than if the expression given in the paper is used, or, as stated above, I fancy the equation on page 717 refers to turbo velocities. As a check on the formula I have the following value from tests on direct-current turbo armatures running at 75 metres per second—

$$t^\circ \text{C.} = \frac{270}{\frac{O}{W}\left(1 + 0.15\,v\right)},$$

which agrees fairly well with the expression given by the authors. I think the authors give a simple explanation of the index law for the air velocity when introduced into the expression for the temperature-rise of coils upon which air is infringing with a velocity v, but I am not quite prepared to agree that the formula in section 6, page 717, is suitable for use in machine calculations, owing to the practical impossibility of estimating the air velocity with accuracy, and therefore I think the more usual, though certainly rougher method of employing an expression of the same form as those previously taken for armatures has something in its favour. Some empirical linear law equations are given below, taken from tests on the field coils of multipolar dynamos; they refer to coils of the ordinary type wound in bobbins and not split into ventilated sections. The surface O is the outside cylindrical

surface, and v is the peripheral velocity of the armature in metres per second. Mr. Catterson-Smith.

Small machines—

$$t^\circ\,C. = \frac{450}{\frac{O}{W}\left(1 + 0{\cdot}02\,v\right)};$$

medium-size machines—

$$t^\circ\,C. = \frac{500}{\frac{O}{W}\left(1 + 0{\cdot}026\,v\right)};$$

large machines—

$$t^\circ\,C. = \frac{540}{\frac{O}{W}\left(1 + 0{\cdot}024\,v\right)}.$$

In dealing with the case of totally enclosed machines it is found that as all the heat has to be dissipated eventually from the outside surface of the carcase the laws of temperature-rise appear to be

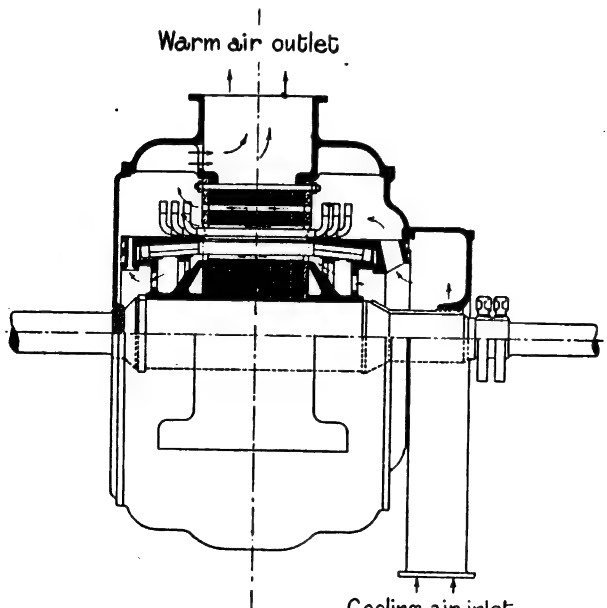


FIG. A.

different, a linear law no longer even approximately holding for armatures; and in the case of field coils the temperature-rise is practically independent of the velocity v. I am glad to state my agreement with the authors as to the great value and interest of the

Mr. Catterson-Smith.

temperature experiments of the National Physical Laboratory presented by Mr. Rayner in 1905.* It was these experiments that first drew attention generally to the temperature gradients throughout windings and to the importance of impregnating the windings with

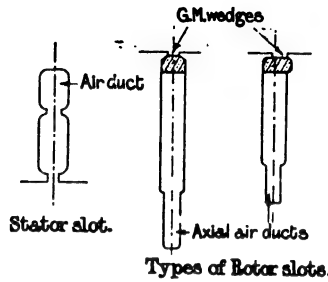


FIG. B.

solid insulating material if the gradient is required to be small. The same idea is present to some extent when field coils are wound with bare aluminium wire, the surface of which is allowed to oxidise. The authors' discussion of the relative merits of axial and radial cooling

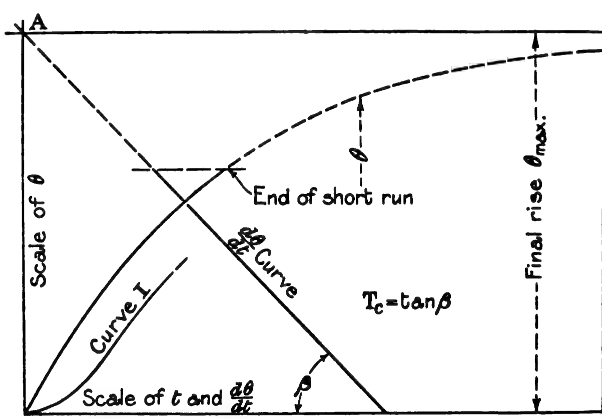


FIG. C.

vents in cores is of particular interest, and in this connection I think Fig. A may be of value as showing a turbo-alternator in which no radial ventilating ducts are employed on the lines of Fig. 16. In order that the heat may be abstracted effectively from the edge surface of the laminations and the under surface of the copper, the punchings for the stator and rotor are in the form of double slots, as shown in Fig. B.

* *Proceedings of the Institution of Electrical Engineers*, vol. 34, p. 613, 1905.

Reference has been made in the discussion to the law of temperature-rise of electric machinery as involved in the problem of the heating of machines on short time runs and load factor duty. As pointed out, the law is often of the form $\theta = \theta_{max.}(1 - \epsilon^{-t/T_c})$, but I should like to draw attention to the fact that it very often departs greatly from this simple law, owing to the complex nature of a machine when considered as a heating body. I think the law of rise of surface temperature of an armature may be regarded as the summation of the law for the several parts in which energy is being lost; that is, for an armature the copper, the teeth, and the core have each their own heating time-constant, and should there be, as is often the case, any great difference in the respective constants, the summation gives a law which is not so simple. Another cause which may be observed for departure from the above law is the fact that at the start there is no temperature gradient across the section of a winding, and thus the maximum rate of increase of temperature often takes place some time after the start, as indicated by curve I, Fig. C. A plan commonly employed on the test-plate for finding a mean value for the constant T_c, checking whether the exponential law is followed in the particular case, and sometimes even for determining fairly closely the final rise without carrying out more than a fraction of the whole run, is to plot θ and $d\theta/dt$ as in Fig. C. The extent of the departure of the $d\theta/dt$ points from a straight line indicates how nearly the simple exponential law is being followed; further, the value of T_c is given by tan β. By producing this straight line to intersect the vertical co-ordinate at A the maximum rise is obtained, as shown by the dotted lines. Mr. Catterson-Smith.

Mr. J. FRITH: One very useful thing that this paper has done is to show how important a part ventilation plays in the design of an electrical machine. Some people, and I am sorry to say some consulting engineers, seem to view a fan in a machine with distrust, as if the machine had come out hot on test and the fan had been added as an afterthought. I have tested machines for one consulting engineer who insisted that if there was a fan on the machine it must be blocked up during test. Throughout the paper it is taken for granted that nothing can be done with the heat until it gets to the surface; but cannot some way be found for controlling the position of the isothermal surfaces, say by putting copper foil between the layers of a shunt winding, in some such way as grading the insulation in a cable? One problem which has not been touched on in the paper is the resistance to the passage of air through an annular space one side of which is revolving, *e.g.*, the air-gap of a dynamo. Another point which I think is worth considering is the use of something other than atmospheric air for cooling entirely enclosed machines, such as turbo-generators; if we let compressed and cooled air into the case of such a machine we could, at any rate, control the final temperature; further, if we used some imperfect gas such as CO_2, there would be a possibility of utilising some of the energy expended in the compression by allowing it to expand into the case and so cool itself. Mr. Frith.

Mr. Faye-Hansen.

Mr. K. FAYE-HANSEN: I am specially thankful to the authors for the tests regarding the heat conductivity of the insulating materials, because I have tried in many ways different sources from which such information ought to be obtainable, but always without finding any data which could be practically used. Regarding the tests themselves, it seems perhaps ungenerous to suggest that further tests should have been made, when one knows the immense amount of work involved in making reliable heat-tests. I think, however, that it would have been advisable to measure the heat conductivity of the material, using at least two thicknesses. In this way the difference in heat resistance, dependent upon the thickness, could be ascertained, and if there is any heat resistance between the surfaces of the conducting materials used inside and outside the insulation material under test and the insulation material itself, it would be eliminated. Regarding the resistance of air-space as shown in Fig. 5, I would suggest that the curve ought to be drawn asymptotic to the horizontal line at the value of 1,800 and not 900, as 900 is a heat resistance between one surface and air, while when the air has to pass from one surface to another it will have to overcome heat resistance from surface to air and again from air to the outside surface. Regarding the heat conductivity found by experiments on machines, I should like to know if in the figure given the authors have taken into account any heat being conducted away from the portion of the winding in the slots to that portion lying outside the slots and exposed to the cooling air. From my reading of the paper this does not seem to be the case, and it would therefore be interesting to know if any appreciable deviation from the results obtained can be expected due to this cause. I would also ask the authors if in practical machines carefully built up they would not expect the specific heat conductivity to be improved with the thickness of the material, as it is likely that the air ducts at the surface between the metals and the insulation material will be proportionately smaller the thicker the material used.

As regards the figuring of conduction of heat along conductors, it is of interest to note that the figuring has been done under the assumption that there are no eddy losses in the windings, so that in practice the temperature-difference will be even somewhat greater than that figured. Coming to the question of the different heating or cooling coefficients for ventilating ducts, field coils and armature surfaces, I personally think that it would be theoretically correct to consider them from one point of view, and that is in the way in which the authors have considered the cooling ducts. Here they have taken the actual temperature-difference between the surface and the air near to the surface and also the speed of the air near to the surface. Neglecting the radiation by heat waves, there is no reason why the figures for armatures and field coils should not be the same if we are able to bring them down to the same basis, *i.e.*, the actual air-temperature and the actual speed relative to the surface. I believe that on this basis the cooling constants will depend on the speed of the air, the condition of the surface and to some extent on the temperature

Mr. Faye-Hansen.

and the specific weight of the air, but will not be influenced by the way in which the relative speed between the air and the surface is being obtained. For obtaining these coefficients, tests regarding the cooling effects of air ducts will of course be the simplest, while in case of armature and field coils it will be necessary to measure, or try to figure, the actual speed of the air along the surface to come to any consistent results. In case of a cylindrical rotor rotating in a cylindrical stator, the relative speed between surfaces and the air can probably be taken to be approximately half of the speed of the rotor.

I also have made some careful tests regarding the cooling effects of ventilating ducts in air-blast transformers, and my results agree with those of the authors in so far that at a given loss the cooling coefficient h_v is approximately proportional with the mean velocity of the air in the ventilating ducts (within the limits measured 3 to 20 metres per second), the ventilating ducts in iron being from $\frac{3}{8}$ in. to $\frac{1}{2}$ in. wide. I find, however, that the more watts to be dissipated per square centimetre, *i.e.*, the higher the temperature-differences, the higher became the cooling coefficient, so that in one given transformer, according to the loss supplied, I got a number of different approximately straight lines. The cooling coefficients obtained by me were, however, considerably smaller ($\frac{1}{2}$ to $\frac{1}{3}$) than those obtained by the authors shown in Fig. 13. This is partly due to the fact that I measured the iron temperature at different places near the air outlet only, as the places at the air inlet were not accessible, and I figured the coefficients on the basis of the same temperature along the whole surface of the iron, the average air-temperature being figured from the measured temperature of the outgoing and incoming air. If the authors had figured in a similar way, their cooling coefficients would only have been approximately 70 per cent. of those shown—in this respect the authors' tests are of course more accurate than my own. The difference seems, however, too large to be explained alone by this, so that I should seek some of the difference in the way the authors have carried out their tests and calculations. In figuring the amount of heat taken away by the air from the punchings, the authors have assumed that all the increase in the temperature of the air in going through the ducts is due to the heat taken away from the iron, while a part of it must be due to the friction of the air against the side of the punchings. As the total windage is approximately equal to the total amount of heat supplied to the air in going through the ducts, the portion of this due to air friction, etc., may be considerable. To this extent the authors have overestimated the cooling coefficients.

Regarding the measurements of the air-temperature it seems also probable that the reading of the thermo-couples will be influenced somewhat by radiation from the iron, so that the actual air-temperature in the slots probably is somewhat smaller than that measured, while it does not seem impossible that the shielding of the thermo-couple against draught when measuring the iron temperature has not been quite efficient, taking into consideration how difficult it is

Mr. Faye-Hansen.

to ensure this in the small space inside the ventilating ducts. It may also be that the actual amount of air has really been more in line with that measured by the anemometer than that figured from the losses and the temperature-rise of the air, as this in leaving probably will not have had exactly the same temperature throughout, so that the average temperature of the outgoing air may have been overestimated. It is also possible that an overestimating of the temperature of the outgoing air has taken place if the thermometer (or thermo-couple) used for measuring this has not been shielded from radiation from the punchings. When it is considered that the cooling constants are figured on a basis of a temperature-difference between iron and air of from 6 to 10° C., and that the kilowatts absorbed by the air are based on a measured increase in air-temperature from also 6 to 10° C., it is clear that a small error in the temperature measurement will give a large difference in the result, and an error of 1° C. in air as well as in iron temperature might correspond to a difference in the coefficient h_v of approximately 50 per cent. From the figuring of h_y on page 689 we obtain h_v (assuming the speed of air along the armature to correspond to half of the rotor speed) approximately half of the value given in the paper. It seems, therefore, as if the authors' tests regarding the actual coefficient to be used in figuring the watts per square centimetre of cooling surface and per degree C. difference of temperature between surface and air are not conclusive, but that further tests ought to be carried out independent of the results obtained by the authors. The tests undertaken by them, as well as those made by myself, prove, however, conclusively that the authors are right in their statement on page 699, that with a given quantity of air passing through the machine the cooling effect will be better the higher the speed employed, so that from a theoretical point of view it is advisable to make the slots used for cooling as narrow as possible to obtain as high a speed as possible. This is, of course, limited by practical considerations regarding the power required for forcing the air through the machine and the heating of the air due to this power. Regarding the question of dirt, however, even narrower slots than those mentioned have been successfully employed, the speed of the air being kept very high.

Mr. Digby.

Mr. W. POLLARD DIGBY: I should like to ask if there is any risk of the values obtained for tightly wound fibrous material being vitiated by the infiltration of films of oil. Again, is there not a risk of uncertainty being introduced by the effect of the infinitesimal air films between them and thick materials? Then, too, could it be safely assumed that the thermal conductivity of insulating materials is independent of temperature, of course within the limits expected by those who design and test dynamos? Finally, has any fatigue effect been observed in the way of a loss of thermal conductivity in the case of fibrous insulating material which has been raised to a temperature that even Dr. Rosenberg would regard as dangerous for, say, untreated cotton?

Mr. J. G. Cunliffe.

Mr. J. G. CUNLIFFE: On the Manchester tramways we often have in connection with football matches, etc., very heavy loading, and

in one district have found it necessary to load the trolley wire to the limit of its safe carrying capacity. The period of loading being short, neither percentage energy loss nor pressure drop is of importance, and the limit is set by overheating, being actually the melting-point of the solder by which the line is attached to the ears. This, of course, has led to very complete and careful investigations into the thermal characteristics of heavy copper conductors at high values of the current density, and in one particular at least the results touch the present paper. Much heat is conducted to the surface of a machine and dissipated there by radiation; it is known to be of importance to provide a dull black coating to the surface in order to assist this radiation, but the extreme value of this coating is seldom realised. Hinlein's curves in Fig. 10 illustrate this value, which is further shown by the following results obtained with new and old trolley wire:— Mr. J. G. Cunliffe.

Specimen.	Nature.	Sectional Area.	Amperes per Square Inch.	Temperature Rise in ° F. after 30 Minutes.	Remarks.
		Square inch.			
A ...	New 4/0 S.W.G. copper wire	0·125	4,800	360	Surface bright
B ...	Old worn ditto	0·120	5,000	285	Upper surface black

The old wire, which had been in service, had a dull black deposit of atmospheric impurities on its upper surface, and the difference in temperature-rise of 75° was due to the superior radiating properties of this film.

Mr. W. CRAMP: I should like to ask the authors one or two questions. It seems to me that in the first part of the paper they set out to construct heat circuit equations comparable to those for the magnetic or electric circuit. They apparently intend to calculate a temperature, a resistance, and a flux. It is a little unfortunate that the term "resistance" is used, as it may lead to confusion between electricity and heat. Even in this paper, which is so lucidly written, occasionally one has to stop and think in order to determine whether electric or heat resistance is being referred to. Having established some of the relationships necessary for these equations, the authors do not proceed to calculate probable temperature-rises on these lines. There does not seem to be any reason why simple machines should not be so worked out and then tested to ascertain how near the theoretical is to the practical result. It would be interesting to know if they have tried such correlation. Again, with regard to the formula recommended at the end of the paper, containing a constant divided by a term involving the velocity. It is not clear to me whether that 333 which the authors use has been compared with the theoretical results occur- Mr. Cramp.

Mr. Cramp. ring in the first part of the paper. Next as regards the actual constant, 333. I worked out some time ago the results published by the National Physical Laboratory, and found that though 333 might be taken as a mean value, yet there were cases in which that constant varied as much as 100 per cent., or nearly so. Is it not somewhat misleading to suggest as a solution a formula which may have such an error? I would like to ask whether the authors intend this formula to apply simply to rotors of turbo-generators, or whether it is not supposed to be applicable to all sorts of rotors? There is next the question of the relationship between the external temperature and the internal temperature of coils. Mr. Rayner has drawn attention to the difference existing in the temperature gradient as between taped coils, varnished and unvarnished. Messrs. New, Levine, and Havill also experimented in the same direction. Their experiments show that the ratio of temperature-rise of the hottest part to the mean temperature-rise was 1·21 when the machine was at rest, and 1·12 when running at full load. The results of tests at the National Physical Laboratory when worked out give the following ratios of mean temperature-rise to rise by thermometer :—

Taped coils, machine light	1·7–2·3
Taped coils, machine loaded	1·9–2·5
Varnished coils, machine standing	1·4–1·8
Varnished coils, machine loaded	1·8–2·2
Coils with taping removed, machine light ...	1·2
Coils with taping removed, machine loaded	1·4

That is to say, that the change of ratio due to varnish alone was of the order of 10 per cent., and in some cases amounted to 20 per cent., which is an extraordinary result. I notice that for measuring their air quantities the authors made use of an anemometer. These instruments are so entirely unreliable that I cannot think the results can be of great value, especially with the apparatus shown.

Mr. Field. Mr. A. B. FIELD (*communicated*): There are two distinct problems involved in the authors' investigation. First, the determination of the specific thermal constants for various materials and surfaces under various external conditions; and, secondly, the actual conditions obtaining in an electric machine. For instance, to determine the watts per square inch per °C. difference of temperature that can be dissipated in a narrow vent with different air velocities, a direct investigation with a small inexpensive apparatus specially constructed with a view to confining the problem to one simplified issue would be the most satisfactory. However, in experimenting upon an actual turbo-generator, the authors have obtained other valuable information besides this particular result. The direct experimental attack on each item separately in these complicated problems is very useful if the results are used with due discrimination. The authors' experiments on the conductivity of various materials illustrates

this, and it is almost to be regretted that they did not have the opportunity to extend the work by a direct investigation of the radiating factors in ducts, both parallel to, and at right angles to, the plane of lamination of the core, supplementing the deductions which they have drawn on these points in a somewhat involved way from the results obtained in an actual machine. The results given in Table II. are very instructive if considered as relative figures, and used cautiously. The difference between solid mica and built-up mica is strikingly shown. It would be of interest to have corresponding figures for the mica under mechanical pressure, as this condition raises the conductivity considerably, and actually occurs in practice, for instance, in turbo-rotors. Our attention is again forcibly drawn to the bad effect of air-spaces, both by the results given in this table and by page 681. The thermal resistance of a 1-millimetre dead air-space is given, and it is of interest to notice that it amounts to as much as that of a 12,000-volt coil insulation. By the impregnation of coils the air-spaces are filled, and the increased thermal conductivity obtained is a not unimportant feature of the treatment. Perhaps the authors should have given a word of caution with regard to Table II. Giving these thermal conductivity values to the third significant figure is apt to induce a false idea of their uniformity. Repeated tests on samples of the same material from different lots supplied by the same manufacturer will generally show very wide variations, almost as wide as between different materials. Again, fibrous materials, such as paper and treated fullerboard, show great differences of conductivity across and in the planes of the sheet, even when under considerable mechanical pressure. In some experiments conducted by Mr. C. E. Skinner, of Pittsburgh, it was found that the thermal conductivity of pure sheet mica was reduced to almost one-half by baking for a short time at 100° to 150° C. —an important result, and one affecting directly the heating of some classes of apparatus after continued service. The experiments on the conduction of heat from the interior of the core to the vent surface are valuable. They indicate that in turbo-generators with radial vents, the vent spacing usually required to give a sufficient air-passage, gives a quite sufficiently uniform temperature through the thickness of each package of laminations. For slower-speed machines, where a wider spacing of vents is usually employed, the pole-pitch is generally much less, and the radial depth of punchings correspondingly reduced, allowing a greater proportion of radiation from the cylindrical surfaces of the core. Radiating surfaces at right angles to the plane of lamination appear to be much more effective than those parallel to the plane, the difference being not fully accounted for by the difference in temperature between the interior of the core and the vent surface. Axial vent ducts have been found very effective partly on this account, and partly because they allow a total section of air-passage which is not limited by the air-gap entrance. As the authors have pointed out, the ventilation of long machines becomes restricted by the area of entrance for the air to the anular air-gap space, and while this difficulty Mr. Field.

Mr. Field. has been satisfactorily overcome by methods of ventilation similar to that shown in Fig. 18A of the authors' paper, there are several advantages in the somewhat simpler method of axial ventilation. In the case of the longer machines the full advantage to be obtained from the radial-slot type of rotor construction cannot be obtained without some other means of ventilation than *viâ* the air-gap alone. Fortunately, with axial ventilation it is possible to adopt a much greater "watts per square inch ratio" for a given temperature rise than with radial vents, and this compensates to some extent for the greater difficulty in obtaining large cooling surfaces (as distinguished from cross-section of vent passages) with axial ventilation than with radial. To illustrate the effectiveness of axial stator ventilation in allowing us to use the radial-slot rotor to its maximum advantage, we may cite the case of a standard 60-cycle 2-pole turbo-generator, in which an 80 per cent. power factor rating of 470 k.v.a. (on the basis of a 50° C. rise guarantee) is obtained from a 12-in. solid rotor weighing only 1,200 lbs., the complete machine weighing, without bearings, only 11 lbs. per kilovolt-ampere; and this rating is limited by the rotor heating, the temperature rise of the stator being considerably below the guarantee.

Mr. Walker. Mr. MILES WALKER (*in reply*): Mr. Law has spoken about the efficiency of the fan. The main part of the losses that occur are due to the skin friction on the surface of the rotor. We find in actual practice that if we take the fan off a turbo-generator and run it we do not get any great reduction in the power taken to drive the rotor. With a fan such as shown in Fig. 18 the power taken to drive the fan is about 25 per cent. of the power required to overcome the windage of the rotor; sometimes only 10 per cent. of the power taken to drive the machine light is taken to drive the fan. It is very difficult to arrive at the efficiency of a fan mounted on the shaft of the rotor. The power taken to drive the fan with full aperture in the experiment described would be about 8 k.w. The main part of the 30 k.w. required to overcome the windage would be absorbed in skin friction on the surfaces of rotor and stator. [Mr. LAW: Can you give us the temperature rise through the fan?] The temperature rise of the air in the end bells is to a great extent caused by the friction of the end bells covering the winding, and also by the heat from the winding that is radiated from the end bells. A certain amount of heat comes from the end-plates of the stator, so that unless we have the temperature of the air exactly as it came from the fan we could not very well get the efficiency. I agree that the efficiencies of the fans that are put on turbo-generators are not at all as great as we would desire. A much higher efficiency is certainly secured by having a specially designed fan driven by a motor. In large alternators it is worth while to do that, but as a rule it is a question of cost. It will be found that a man will not pay £60 or £70 for a special installation of a motor fan in order to get a small increase in efficiency. I do not agree that the amount of the efficiency can be increased by 10 per cent., because the actual loss in the fan of the machine is a very small loss indeed. With regard to the

losses in the centre of the machine being greater or less than at the end, I agree with Mr. Law entirely. There are certain circumstances under which the losses in the ends are greater than in the middle. We know, for instance, that the flux passes from sheet iron into the end-plate and very often causes a loss; there is a leakage field from the end of the rotor which attacks the end-plate and causes loss. Sometimes these losses are considerable, but we generally find that if a generator is built with ventilating ducts evenly spaced all along the temperature rise in the centre is a good deal greater than at the ends. That is due, of course, to the fact that the air is heated as it passes through from the ends. The ends are fed with cool air. For that reason it has been common practice to make the ventilating ducts in the centre closer together than at the ends. That partly accounts for the smaller difference of temperature between the iron and the air in the centre of the machine. With regard to the cases referred to in Figs. 27 and 28, it is true that there is rather a small difference between the air coming out and the iron which is in the centre of the machine, but that I attribute mainly to the fact that with the very large amount of air passing through, and the ventilating ducts being very close together, they cool the iron down almost to the temperature of the air without much difficulty. At the ends of the machine the temperature difference in the iron will still be found to be less than in the other tests, but because the ventilating ducts are not so near together as the ends we have a greater difference of temperature between the iron and the air. I still think there is a good deal that is not understood in this temperature distribution that is found in turbo-generators. Sometimes we get very strange temperature distribution. Mr. Walker.

With regard to the question of water-cooling, I intended to make the same reply that Mr. Glendenning has already made, namely, that water-cooling has been tried, and the difficulty is that the customer does not want it. The Allgemeine Company have built turbo-generators of considerable size with water-cooling; they pass the water into the frame. I think that for very large machines it will be used, for with very large machines it will pay to have a proper system of pipes which can be made thoroughly watertight. There must be no question about the watertightness of the pipes. Water-cooled transformers are made successfully because the pipes used are of drawn copper tube. If there is a joint it must be superlatively well made, because there must not be any risk of a leak. With regard to oil immersion, that has also been considered, but it has been found that the difficulties that Mr. Rayner suggested have been so great that nobody has carried it into practice. Some day it may be done. Pumping oil through a conductor has been carried out in coils, in which it is desired to get rid of a great deal of heat from a very small coil.

I was amused at Mr. Rayner's remarks about the anemometer, because that anemometer was calibrated by the National Physical Laboratory. The method of measuring the air by measuring the temperature is, I think, one which can be used with fair accuracy in

Mr. Walker. practice. As a matter of fact, we checked the anemometer in all the tests by taking very careful temperature readings of the air coming in and the air going out. We thought that would be as good a check as we could get.

The figures from certain experiments on coils given by Mr. Everest agree as closely as can be expected with the figures given in Table II. It will be seen that cellulose fibrous materials, whose pores have been well filled with varnish, have a heat conductivity (expressed in the units given in column 10) of about 0·004 watt per square inch per °C. of temperature per inch length of path. For instance, treated rope paper is given as 0·0042; a sample of empire cloth which was wound on a cylinder so tightly as to exclude air-spaces came out as high as 0·0063; while a sample of treated linen tape with which no special precautions were taken was only 0·0037. If we take 0·004 as an average figure, this gives us 250° C. rise for 1 watt per square inch, a figure in close agreement with the cases cited by Mr. Everest. The figure given for varnished cloth cannot be expected to be reached in practice because it is not likely that in the ordinary wrapping process in the shops all the air will be excluded, but it is interesting to have a test on varnished cloth to see how good the conductivity can be made. I am obliged to Mr. Everest for his correction of the figures relating to Fig. 7. The mean perimeter is 5·3 in. and not 6·8, so that the specific conductivity of the insulation works out at 0·00145 instead of 0·00112. The new figure is more nearly in agreement with other figures in the paper. I agree with Mr. Everest in what he says about the equivalent zero of resistance. The zero for the formula given in the paper should not be 273, but some other figure depending on the part of the curve for the specific resistance to which we should draw the tangent which represents the law most nearly over the range within which we are working. I will look into this point and revise the formula accordingly.

In reply to Mr. Sack, I would point out that the reason why the materials measured by Bacon's method give high readings is that the materials were in solid sheets and therefore free from air-spaces. It was not possible to wrap these sheets around a tube, and that is why a different method was adopted. One of the main objects of the table is to show the different heat conductivity of the same materials when mounted in different ways.

In reply to Mr. Glendenning, I would point out that we have given the data in the tables in both systems of units for general convenience. In other parts of the paper we have not thought it worth while to convert to both systems, as it is sufficient to give in one system or the other the facts upon which our deductions depend.

I agree with Professor Thornton that it would be of interest to work out the temperature rise on a machine from the rules and compare it with the figures actually obtained. We hope in the future to do this.

While Mr. Roberts is right in calling attention to the large amount of power lost in air friction in turbo-generators, he is wrong in supposing that any considerable portion of this occurs in the ventilating ducts.

Mr. Walker.

The main part of the loss is caused by two circumstances. One of these is that the air in passing through the fan or rotor is given a high velocity which is afterwards lost in eddies. The other is that the high velocity of the cylindrical surface of the rotor causes a very great deal of skin friction. In one experiment the machine was run for 4 hours with no excitation and no loss except windage. After the temperatures became steady it was found that the air in the gap had an average temperature rise of about 10° C., while no difference of temperature could be detected in an ordinary thermometer between the entrance and exit of the duct.

It is useful to have the data given by Mr. Catterson-Smith for the cooling armatures, especially as he has been careful to state exactly how the surface is estimated. The fact that the so-called "constants" differ so widely shows that these formulæ connecting temperature rise and velocity can only be used successfully when the constants have been determined for a particular type of machine. The method given of determining the approximate final temperature rise by means of data derived during a short test will often be useful in saving time and power.

Mr. Faye-Hansen's criticism as to the importance of carrying out tests on several thicknesses of material is justified from an inspection of Table II., but as a matter of fact that table only gives a small part of the results that were obtained. Tests were made of four different samples of untreated rope paper which were, in fact, of different thicknesses, and the results agreed sufficiently well between themselves. No attention is called in the paper to the absence of surface resistance in heat conductivity, as that point has already been dealt with in the paper by Mr. Bacon referred to. The reason why we have taken the curve in Fig. 5 as an asymptote to the horizontal line at 900 is that our experiments were carried out on a cylindrical air-space, and as we increased the size of the gap the diameter of the outer surface bounding the air-gap became greater and greater; so in the limit this surface would become infinite and the thermal resistance on that surface zero. We therefore had in mind only the constant resistance of the internal surface. Still, Mr. Faye-Hansen is right, and our curve would have to be modified if it were applied to the case of an air-gap between two flat conducting surfaces. Referring now to Fig. 7, and the temperature rises given in connection with that figure, it will be seen that the temperature rise at R was 39° C., and at U, 38° C. This shows that the temperature at the corner of the coil is so nearly that in the slot that not very much heat would be conducted outwards. In calculating thermal resistances of either thin or thick insulations allowance should be made for the probable air-gap between the insulation and the iron. It is quite possible that the cooling coefficient 0·0014 given in our paper is a little high for the reasons stated by Mr. Faye-Hansen. The effects he speaks of are, however, very slight. In the experiment cited above in which the air though heated up about 10° by friction before it left the air-gap received no appreciable warming in the ventilating ducts, showed that the air friction in the ducts is very slight. This is what would be expected. If we blow air at a velocity of 5 metres per second

Mr. Walker. through a ⅜-in. duct for a distance of 11 in. we should not expect to get an appreciable rise in the temperature of the air. Still the effect is there, as in the other possible sources of error pointed out, and though very small, should perhaps be taken into account.

In reply to Mr. Pollard Digby, I may say that some of our experiments were completely spoiled by the infiltration of oil and had to be repeated on that account. The effect of air films will always be to cause uncertainty in the calculation of thermal conductivity of insulation.

I agree with Mr. Cramp that the formulæ for the cooling of revolving cylinders are far from satisfactory. Our experiments were not expressly directed to the problem of revolving cylinders. All we have done in the paper is to collect some of the best-known formulæ on the subject and to apply one of them to a particular case which arose in our experiments. So far as we can judge, the formula given by Ott is as good as any formula can be which does not take into account all the circumstances controlling the temperature rise. Ott's formula also agrees very closely with that given by Arnold.

I agree with Mr. A. B. Field that it would be of great interest to make further experiments by means of a specially constructed piece of apparatus on the rate of passage of heat from the walls of radial ventilating ducts and of axial ducts so that the two systems of ventilation could be compared and further data obtained. I will take the earliest opportunity of carrying out some experiments of this kind. I think that it is perfectly clear from Tables I. and II. and the nature of the experiments that the figures given for conductivity are not to be read to the third or even the second significant figure. The results have been worked out on a slide-rule, and one naturally puts down the reading of the slide-rule as the result of the experiment.

Reference is made to results obtained by Mr. C. E. Skinner. These results, I understand, are shortly to be published in America. They confirm the results given in Table II. Here are some of them :—

	Watts per Square Inch per 1° C. per Inch Length of Path.
Varnished cloth	0·0050 to 0·0060
Varnished fullerboard	0·0032 „ 0·0038
Treated rope cement paper	0·0035 „ 0·0042

The reduction of the heat conductivity of mica after it has been heated up is to be expected if the heating occurs under such circumstances as to open out the laminæ and introduce air-spaces. If no mechanical separation of this kind occurs I do not think that the heat conductivity will be affected, for mica is formed at a much higher temperature than 100° C., and its physical state will not be changed by such a low temperature unless the heat is applied so as to cause disintegration by uneven expansion. The pieces of mica which we tested were specially chosen for their freedom from air-spaces. There were just a few cleavages near the edges of some of the pieces, and then there were the air-spaces between the three successive sheets.

Proceedings of the Five Hundred and Thirty-sixth Ordinary General Meeting of the Institution of Electrical Engineers, held on Thursday, 14th March, 1912—Mr. S. Z. DE FERRANTI, D.Sc., President, in the chair.

The minutes of the Ordinary General Meeting, held on 7th March, 1912, were taken as read, and confirmed.

Messrs. A. T. Morris and F. Creedy were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

As Associate Members.

Herbert Ambrose Cope.
William Copeland.
Ralph David Given.
William Richard Hackworth.
Harry Holliday.
Charles Hubert Montgomery.
Wilson Ormrod.
Hiroyoshi Oshima.
George Lewis Rosser.
Robert M. Russell.
Stanton Swire.
Charles George Watson.
William Young.

As Associate.

Frederick George Sneath.

As Students.

Mohamed Soliman Abdullah.
Victor Atkinson Bright.
Alfred George W. Brookes.
Guy Henry Champ.
Ishwarlal Bhogilal Damania.
William Gibson.
Norman Greenep.
Robert Macfarlane McNaught.
Stanley Bantock North.
Cleveland Garfield Richards.
Charles Frederic W. Sedgwick.
Thomas Sloan.
Sri Krishna Srivastava.
Douglas Carter Stern.
Sam Wilkinson.
Lew Chai Yau.

Donations to the *Library* were announced as having been received since the last meeting from The Boswell Printing and Publishing Company, Ltd., A. Constable & Co., Ltd., The Electrician Printing and Publishing Company, Ltd., W. T. Glover & Co., Ltd., E. and F. N. Spon, Ltd., and Whittaker & Co., Ltd.; and to the ***Museum*** from The Automatic Telephone Manufacturing Company, Ltd., A. Coleman, and H. F. D. Jacob, to whom the thanks of the meeting were duly accorded.

A lecture, with lantern slides, entitled, "Notes on an Avalanche which occurred on the Wellington (U.S.A.) Tunnel Electric Railway," was delivered by Mr. T. Stevens, Member.

The meeting adjourned at 9.10 p.m.

DYNAMOS FOR MOTOR ROAD VEHICLE LIGHTING.

By J. D. MORGAN, Associate.

(*Paper received 13th September*, 1911, *and read before the* BIRMINGHAM LOCAL SECTION, 10*th January*, 1912.)

INTRODUCTION.

During the past few years serious attention has been directed to the development of electric lighting systems for motor road vehicles, as it is widely recognised that something superior to the ordinary methods of oil and acetylene lighting is urgently needed.

The problem presented is a threefold one, being concerned with the form and arrangement of the optical parts of the lamp, the disposition of the filaments in the lamp bulbs, and the generation of current. In the present paper the object is to discuss briefly the subject of current generation, giving a short account of the most notable work which has recently been done, and of tests made by the author on machines of representative types.

By common consent the use of a battery alone for providing current is unsuitable, and a dynamo is essential. The construction of a suitable dynamo presents peculiar difficulties, and the crux of the lighting problem is connected mainly with the dynamo.

The principal conditions to be complied with are: (*a*) That the dynamo must be capable of maintaining a practically constant voltage over a wide range of speed variation and under different loads; and (*b*) if voltage variations are unavoidable, the amount of variation must not seriously affect the brightness of the lamps. Regarding the first condition, it is usual to arrange for the dynamo to supply current at the normal voltage when the vehicle is moving at the rate of from 10 to 15 miles per hour, and to maintain the voltage constant, or as nearly constant as possible, at all superior speeds, which may reach 50 to 60 miles per hour. When the vehicle is at rest or travelling below 10 miles per hour the current is supplied entirely or for the greater part by a battery arranged in parallel with the dynamo circuit. Regarding the second condition, it is known that in metal filament lamps a small increase above the normal voltage is attended by a relatively large increase of brightness. The results of an experiment on a 4-volt lamp are shown

in Fig. 1. It will be seen that an increase of the voltage from 4 to 5 caused the candle-power to increase from 3·6 to 8. The curve is not intended to provide an absolute measure of the candle-power produced under a given voltage, but to indicate the kind of change which is experienced. In the experiment two identical lamps designed to produce 4 c.p. at 4 volts were used. One was supplied with current at constant voltage and the other with current at different voltages, and the two were compared by a simple photometer. Variation of brightness with variation of voltage differs considerably in different lamps, but in all the samples tried the variation was found to be large. In an experiment by Mr. G. A. Shakespeare at the Birmingham University an increase of from 8 to 8·8 volts in an 8-volt lamp caused an increase of candle-power from 14½ to 26.*

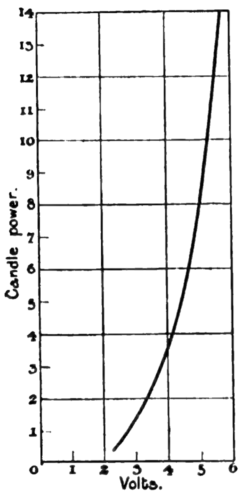


FIG. 1.

Many proposals and attempts have been made to construct dynamos complying with the above conditions,† but in the present paper only a few leading representative types which have actually been reduced to practice are considered.

In passing it may be well briefly to anticipate a familiar criticism that there is little or nothing new in the problem of the dynamo for motor road vehicle lighting, as it is strictly analogous to that of the dynamo for train lighting, upon which a large amount of valuable work has been done, and that what is suitable for the one is also suitable for the other. To some extent this is so, but the task before the manufacturer of motor vehicle dynamos presents peculiar obstacles in that simplicity, compactness, and reliability must be obtained in a much higher degree than is essential for train lighting where skilled supervision is constantly exercised.

ELECTRICALLY REGULATED DYNAMOS.

A method of regulation which forms the basis of several known types of electrically regulated machines consists in the use of a separate counter-exciting dynamo adapted to diminish the excitation of the principal machine in such a manner that the field of the principal machine varies inversely as the speed. This device is obviously objectionable on account of the duplication involved.

Several attempts have been made to construct machines in which a series compensating winding is used, the idea being to diminish the

* Marks and Clerk, "Electric Lighting for Motor Cars," p. 80; Appendix by G. A. Shakespeare, 1911.
† Ibid., Chapters I. to IV.

strength of the field progressively by the current in such winding after the normal voltage has been reached. Obviously a constant voltage cannot be obtained, but what is aimed at is to keep the voltage variation within practical limits over a given range of speed variation. A machine embodying this principle for road vehicle lighting is produced by Messrs. Bleriot, Ltd., and is illustrated diagrammatically in Fig. 2. The arrangement differs from the more familiar devices of this type in that the shunt winding *a* is connected across the external circuit, and the current leaving the armature passes through the series winding *b* before reaching the shunt winding. A centrifugal switch at *c* closes the external circuit when a certain speed is attained. Usually the arrangement is identical with that of an ordinary compound-wound dynamo, excepting that the series winding acts in opposition to the shunt winding. By the Bleriot method a much larger voltage variation can be produced at the brushes than is experienced in the external circuit,

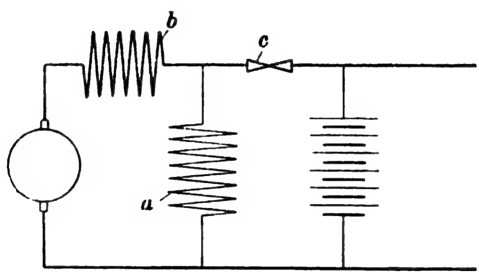


FIG. 2.

and the current through the shunt winding is subject to smaller fluctuations than it would be if connected across the brushes. Consequently a greater compensating effect can be obtained from the series winding than would otherwise be possible. A representative result selected from a large number of tests made upon a Bleriot machine is shown in Fig. 3. The machine was intended to supply lamps consuming about 12 amperes at 12 volts, but was designed to give out as much as 25 amperes. In the experiments the battery used was a set of six Fors cells of 50 ampere-hours capacity (a size commonly used in motor-car practice). The range of speed variation over which the machine appeared to be useful was not as large as might be desired. It will be observed that between the speeds of 1,600 to 4,000 revs. per minute the voltage rose from 10·5 to 13·75 and the current increased from 6 to 18. Over the same range of speed variation the voltage at the brushes rose from 11·5 to 16·75. The increasing difference between the two voltage curves illustrates clearly the usefulness of the arrangement of the windings in the Bleriot machine for regulation purposes. If the shunt winding had been connected across the brushes the two curves would

probably have been nearly parallel and a larger variation of voltage would have been experienced in the external circuit.

As a result of the test it may be urged that the performance of the Bleriot machine was not satisfactory. But it is possible that with a larger battery or a machine designed to give a smaller output at the same voltage better regulation would have been obtained. When determining the output of machines of this type makers generally appear to be faced by the difficulty that if the size of the machine is reduced there is a danger of excessive heating, whilst if liberal proportions are adopted the regulation is impaired.

A further result of the test was a demonstration of the fact that the regulation of the machine is dependent on the condition of the battery.

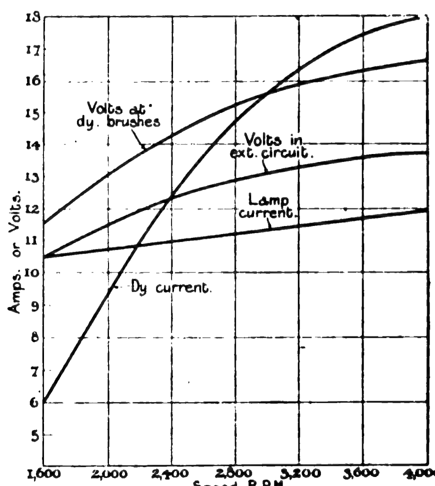


FIG. 3.

At the higher speeds the current given out is much larger than that consumed by the lamps, and in consequence a heavy surplus is directed into the battery. With the battery run down superior regulation to that shown in the diagram was experienced, but when the battery approached the fully charged condition the voltage in the external circuit increased without increase of speed. Thus, in one experiment the voltage in the external circuit increased from 15 to 20 without any alteration of speed, this being due apparently to change in the condition of the battery. Obviously to get the best results the current given out should approximate more closely to that required by the lamps, and this observation applies generally to all types of machines. It is sometimes urged as an advantage that certain machines are capable of giving current largely in excess of requirements. Ap-

parently this is fallacious; it is a disadvantage rather than an advantage. The best results as regards steadiness of voltage are obtained when the maximum output does not exceed the consumption by more than about 2 or 3 amperes. With some batteries this figure may be increased, but in all cases a heavy charging current should be avoided.

Fig. 4 illustrates the performance of the same machine under a smaller load. The principal observation to be made thereon is that the voltage variation in the external circuit is greater than before and, in fact, is excessive.

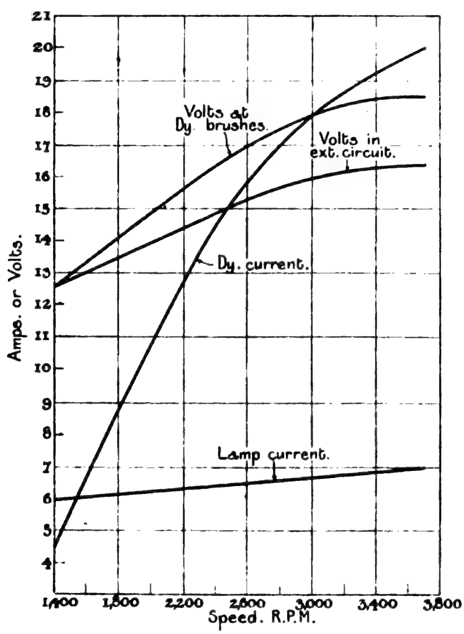


FIG. 4.

One other point of importance to be noted in both cases is the small variation in current consumption by the lamps. As this point is of general importance it will be dealt with later. For the present it will only be remarked that all machines which are regulated automatically by an increase of current in some part of the system which is in communication with the external circuit appear to be useless without a battery.

From the foregoing account of the Bleriot machine it might be inferred that superior regulation could be obtained by separately exciting the field windings from a battery or other source of constant potential, or by using permanent magnets. The author believes that

machines constructed with permanent magnets and a regulating series winding have been placed on the market for motor-car lighting, but he has not been able to obtain one. It would be rather surprising to find that they were serviceable, for the winding must exercise a demagnetising effect and in time render the magnets useless. Regarding the use of a separate exciting battery, this would obviously

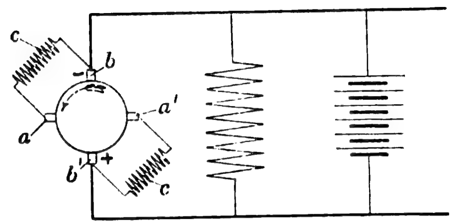


FIG. 5.

be objectionable on account of the extra battery required and the additional attention necessary for keeping the battery in proper condition.

An exceedingly good and interesting machine of the interbrush type is that of Messrs. Trier & Martin, which is illustrated diagrammatically in Fig. 5. The machine is of two-pole shunt wound con-

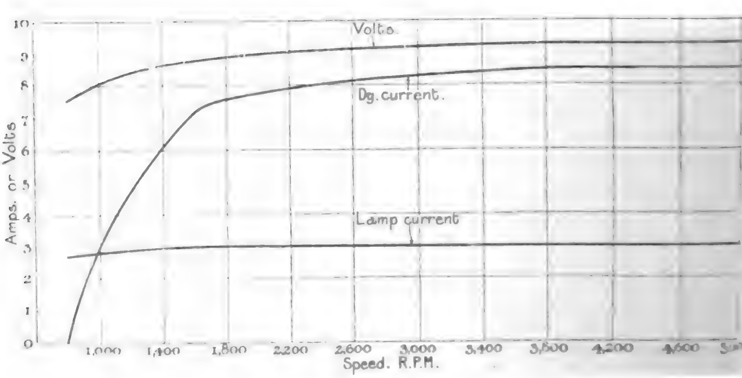


FIG. 6.

struction, and is provided with a pair of intermediate brushes *a a* placed midway between the ordinary main brushes *b b'*. The main and interbrushes are connected together through resistances *c*. It will be observed that the arrangement differs from the more familiar Leitner arrangement in that the interbrushes are connected to the main brushes instead of to the field windings. The makers describe the action of the machine in their patent specification as follows: "As

b is the negative and *b′* the positive brush, the current in the resistance connecting the main brush *b′* with the auxiliary brush *a′* will, when the machine is running on open circuit, flow from *b′* to *a′* and, in the resistance connecting the other pair of brushes, will flow from *a* to *b*. The effect of these currents, which of course also flow in the armature coils between *b′* and *a′*, and *a* and *b*, is to strengthen the main field. As the load increases, an armature reaction is set up which displaces the axis of the field forward and by so doing reduces the current in the resistances *c*, and consequently the magnetic field is also reduced. When the axis of the magnetic field is displaced by 45°, there will be no current at all between the main and auxiliary brushes, as they will then be at equal potentials. A further displacement of the magnetic field due to increasing load and speed will cause a current to flow again between the main and auxiliary brushes, but such current will now be in the reverse direction and its effect will be to weaken the main field instead of to strengthen it. Thus the output of the dynamo becomes self-regulating."

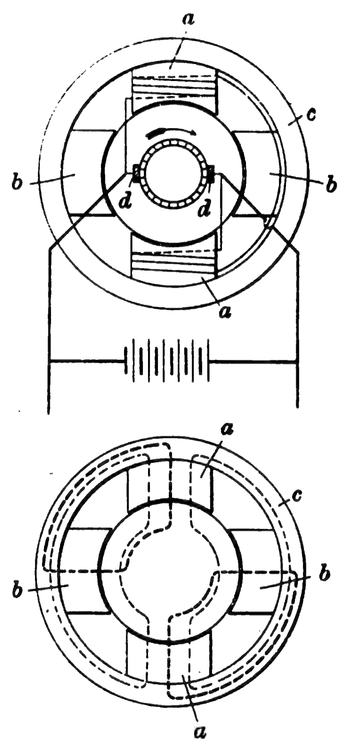


FIG. 7.

Regarding the performance of the machine, this is illustrated in Fig. 6. In the tests an 8-volt battery was used. The output rapidly rises until a speed of about 1,600 revs. per minute is reached. Above this speed the output rises very slowly and keeps within a practical limit. As with other self-regulating machines, a battery is essential, and the maximum voltage and current obtained depends to some extent on the condition of the battery. The variations with changes in lamp load are insignificant. In the experiment recorded, cutting out all the lamps caused an increase of the maximum voltage of ½ volt and a diminution of current of less than ½ ampere. With lamps consuming 4½ amperes the maximum current given by the machine was 8 amperes.

Another interesting machine is the Midgley-Vandervell, or C.A.V. machine. This is of the type with which electrical engineers have been familiarised by the Rosenberg machine, depending for its self-regulating property upon the short-circuiting of certain armature windings. The principle of the C.A.V. machine is illustrated in

Fig. 7, where the upper view shows the connections and the lower one the magnetic system alone. Two opposite pairs of poles *a* and *b* are united by the body *c*. The poles *a* are provided with shunt windings, whilst the poles *b* are left unwound. Current is supplied to the external circuit by the armature windings under the poles *b* through brushes *d*, and the armature is wound in such a manner that the brushes also short circuit armature coils lying in the neighbourhood of the leaving edges of the poles *a*. The initial path of the magnetic flux is indicated diagrammatically by the thin dotted lines in the lower figure. When the current in the short-circuited coils reaches a certain value, the magnetism associated with them appears to break down the principal flux at the parts adjacent to those coils, and causes the flux to swing into opposite quadrants as indicated by the thick dotted lines

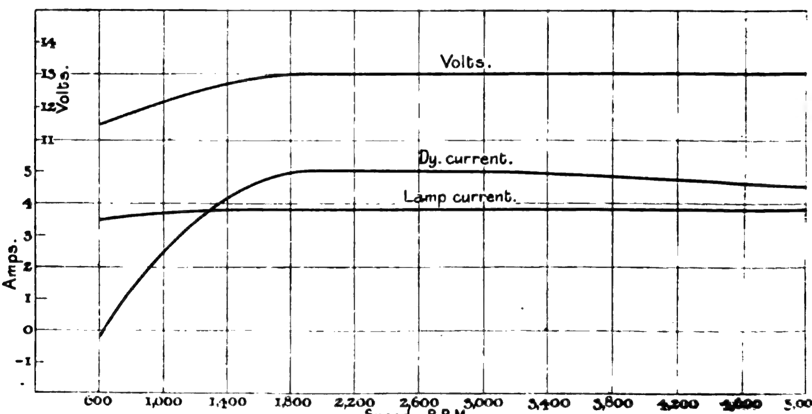


FIG. 8.

in the figure. At this stage the machine becomes self-regulating, as the cross-magnetisation due to the armature coils under the poles *b* counteracts the principal flux and so progressively weakens the field as the speed increases. This action proceeds to a limit beyond which under a given load the voltage and current are constant at all speeds.

The above explanation is based upon information contained in the inventors' patent specification, but whilst apparently satisfactory as a general guide to the action of the machine, it does not appear to be complete, for long before a marked change occurs in the disposition of the flux, current is supplied to the external circuit, which suggests that the two dispositions of flux shown in the figure exist concurrently at all speeds.

The behaviour of a machine in practice is shown by the diagram in Fig. 8, which is representative of a large number of tests with the

machine coupled to a battery and lamps as in service conditions. It will be observed that when the maximum voltage is reached it remains remarkably steady. A drop is shown in current at the higher speeds. This is probably due to defective brush contacts. It will be observed that the maximum current directed into the battery was 1·2 amperes. With such a small charging current a practically uniform condition is maintained in the battery, and the latter is therefore not so likely to interfere with the regulation of the machine as when a machine is used the output of which is largely in excess of the demand. The lamps used in the test were two 12-volt head lights in parallel and three 4-volt side and tail lights in series. Using the head lights only the maximum volts increased from 13 to 13·5, and using the side and tail lights only, the maximum volts rose to 14.

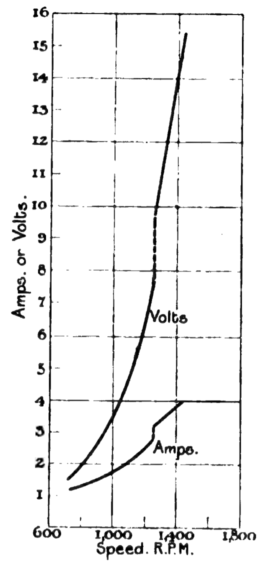


FIG. 9.

The C.A.V. machine also requires the use of a battery before its self-regulating property can be asserted. Fig. 9 is a typical illustration of the action of the machine when used without a battery. This is not given in any spirit of adverse criticism, but chiefly as a matter of interest in that it shows, in a manner which is not evident when a battery is used, the abrupt change which occurs at a certain stage in the magnetic condition of the machine. No two tests give similar curves, but all show a marked discontinuity when about 7 or 8 volts is reached. This suggests, as has already been indicated, that the two dispositions of the magnetic flux exist concurrently at all times and in a manner which is not susceptible to direct control.

Referring again to the inability of the self-regulating machines here discussed to operate without a battery, it will be observed that in each case a rapid increase of current and a comparatively slow increase of voltage is obtained during the slower speeds of the machines. Without this, self-regulation cannot be obtained, for it is upon the production of a large increase of current with a comparatively small increase of voltage that the machines depend for their action. It follows, therefore, that if the required variations of current with changes of potential cannot be obtained, the machines lose their characteristic. In each case the regulating current flows in a circuit which is in communication with the external circuit, and unless a large increase of current can be discharged into the external circuit with increase of voltage, insufficient current is obtained in the regulating circuit, and in consequence the voltage of the machine rises

rapidly with increase of speed. This is what is experienced when lamps only are provided in the external circuit. It is found that owing to the variable resistance of metal filament lamps an increase of voltage at the lamp terminals is not attended with a proportionately equal increase of current. Generally speaking, in all the lamps tested by the author, a 100 per cent. increase of voltage is attended by only a 50 per cent. increase of current (these figures being an average approximation). Therefore in a group of lamps using 5 amperes at 12 volts, an increase of volts to 14 (which, though common in practice, is excessive) is attended by an increase of current of only 0·4 of an ampere. But when a battery is used such an increase of voltage is attended by a proportionately larger increase of current passing through and from the machine, and in consequence self-regulation can be obtained. This fact is of great importance, inasmuch as it makes the battery an indispensable part of the equipment. At present this is of little consequence, but if, as some engineers think, it should

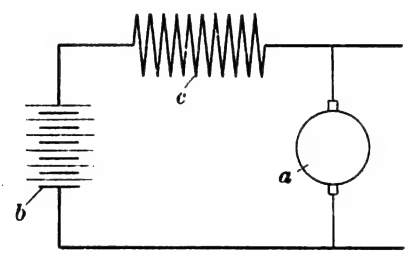


Fig. 10.

eventually be considered necessary to dispense with the battery, then machines of the type above described would be useless. The practical conclusion is, therefore, that in self-regulating machines depending for their action upon an increase of current, either they must be adapted to operate with a very slight increase or they must be so designed that a heavy regulating current can be produced in some part of the machine which is quite independent of the external circuit.

Another interesting self-regulating system is that of Grob, shown in Fig. 10. The machine *a* is separately excited by a battery *b*, and the field windings *c* are connected between the positive poles of the battery and machine respectively. With increase of voltage across the brushes the difference of potential at the ends of the windings diminishes, and in consequence the strength of the field diminishes. This action rapidly proceeds to a limit above which the voltage and output of the machine under a given load remains fairly constant at all speeds. The system appears to be capable of giving good results, but it possesses the serious disadvantage that a battery of twice the normal size must be carried in order that one-half may be charged whilst the other half

is in service. Further, the permanent or residual magnetism of the machine seems to prevent a perfectly steady voltage from being obtained.

Mechanically Regulated Dynamos.

Mechanically regulated dynamos depend for their action upon some moving part. A number of different methods of mechanical regulation are known. Whilst only one or two are of any practical value for road vehicle service, a few of the more familiar methods are here mentioned as objects of interest. In one machine the armature is moved axially by a governor, so that the number of lines cut by the armature winding varies practically inversely as the speed. In another machine the air-gap is widened or contracted, either by the use of governor-controlled hinged pole-pieces, or by a conically shaped armature which moves axially under the action of a governor between conically shaped pole-pieces. Sliding masses of iron for varying the flux through the pole-pieces have also been proposed. The idea of shifting the brushes automatically seems to have been popular with inventors, and a machine embodying the equivalent idea of swinging the machine relatively to fixed brushes has been notified in the press, if not actually put on the market. A very common method of regulation consists in the use of a field regulator actuated by a governor. This is undoubtedly a simple and practical procedure, having one or two possible advantages in its favour, but the difficulty appears to reside in the production of a sufficiently simple regulator capable of withstanding the conditions experienced on the roads. Inventors working in this direction usually favour a combination of a governor and a switch arm, but obviously this is too complicated and not so good as other devices in which a governor is used for performing a different function. For example, the combination of a governor and a slipping clutch gives excellent results and is very simple, as will be shown hereafter. If a field regulator is to be successful, it must show advantages over the slipping clutch, and in consequence some means other than a governor appears to be required for its operation. For this purpose a fixed and moving coil system might be used in conjunction with an arrangement of windings whereby a change of current causes the switch arm to take up a new position. The difficulty lies in making such a device sufficiently sensitive without sacrificing durability and immunity from road shocks and vibrations. The electrical condition which a field regulator must comply with is very simple if the dynamo is worked well in the region of magnetic saturation, and is one which can readily be followed in an automatic regulator. Fig. 11 shows the relation between speed and total resistance in the field-winding circuit over a fairly wide range in the particular shunt-wound machine upon which the experiment was made. Doubtless by appropriate modification of design the range could be much increased. Further, any slight departure from the straight line could readily be allowed for in the arrange-

ment of the regulator coils. In the experiment represented in Fig. 11, the volts remained consistently at 12, whilst the amperes increased from 4·5 at the lower speed to 6 amperes at the higher speed.

The most important of mechanical devices hitherto produced for regulation purposes are those depending upon a slipping drive. These are divisible into two classes, which are characterised respectively by constant torque and constant speed. Engineers have long been familiar with a notable instance of constant torque in the Stone machines, which employ a slipping belt. In view of the extensive use and excellent service of these for railway-train lighting, it is natural to consider whether they are equally applicable to motor-car lighting. Apparently they are not. In the first place, it is generally expected that as soon as electric lighting on motor vehicles becomes extensively adopted, provision will be made by builders for direct connection of

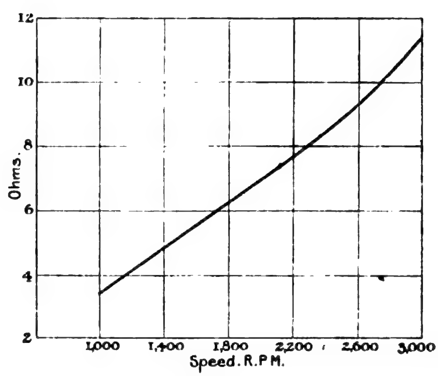


FIG. 11.

the dynamo to the engine, as for the magneto. This would at once make the use of a belt inconvenient, if not impracticable. In the second place, a constant torque device is wrong in principle for motor-car lighting. No doubt tolerably good results could be obtained, but development could never reach perfection on account of the inherent unsuitability of the device for this particular service. The problem before the designer is to keep the voltage at the lamps as constant as possible. Assuming that a constant torque mechanism is adjusted to slip under full load at a given speed, then if the load be reduced considerably, the speed of the dynamo will at once increase, and this will result in increase of voltage, which, although it may be prevented by a suitably proportioned battery from becoming excessive, can never be avoided. In motor-car practice it is common to arrange the side and tail lights in series under the control of one switch, and the head lights (if two are used) in parallel under the control of another switch. To cut out either set of lamps causes a big difference in the lamp load,

and is, in consequence, attended by an increase of speed in the dynamo and of brightness in the remaining lamps. It may be urged that variations at the lamps can be kept within practical limits, especially when a battery is used, but the point which it is here desired to emphasise is that the constant-torque device must always be imperfect for motor-car service.

As regards constant speed devices, these usually consist of a governor-controlled clutch. An exceedingly good form is one constructed by Messrs. Joseph Lucas, Ltd. Fig. 12 shows a section of the clutch. A driving pulley *a* is arranged to run freely on the armature shaft *b* and is shaped at one end to contain a number of free governor balls *c*. The latter are supported in slots in a plate *d* keyed to the armature shaft, and are arranged to bear against the inner surface of a

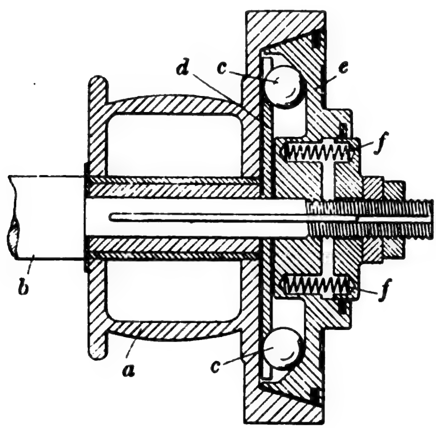


FIG. 12.

clutch element *e* which whilst secured to the shaft can slide thereon. The inner periphery of the pulley is shaped to correspond with the outer coned periphery of the part *e*, and between the two surfaces is inserted a thin ring of vulcanised fibre. Springs *f* serve to keep the clutch in action. At and below a certain speed the mechanism revolves as one piece, but above that speed the balls, by their centrifugal action, relieve the pressure due to the springs between the clutch surfaces and enable slipping to occur. There is no appreciable separation of the clutch surfaces when in action, but simply a variation of pressure. It will be observed that the balls are connected to the driven part and not the driving part of the mechanism.

As might be expected, a jerkiness of action is a common fault in slipping clutches at the critical speed owing to the difference between static and kinetic friction, and a drop in speed is often experienced at the instant when slipping begins; or, in other words, the clutch can

continue to accelerate the speed of the armature beyond the maximum speed for which the clutch is adjusted, but as soon as slipping sets in the speed drops and remains tolerably constant at all superior speeds of the driving pulley. Messrs. Lucas have avoided this defect by arranging for ample lubrication of the clutch surfaces so that they are always separated by a thin film of oil. By this provision the instant at which slipping occurs becomes practically imperceptible, and an extremely smooth action is obtained. Fig. 13 illustrates the results of a series of tests made on a Lucas dynamo fitted with a clutch of the type above described. It will be observed that the maximum output remained perfectly steady. With variation of load an increase of the maximum dynamo speed was obtained and a consequent increase of voltage. When supplying current (3·8 amperes) to two 12-volt head lights and three 4-volt side and tail lights the maximum voltage was 13. On cutting out the side and tail lights the voltage increased to 13·6, whilst

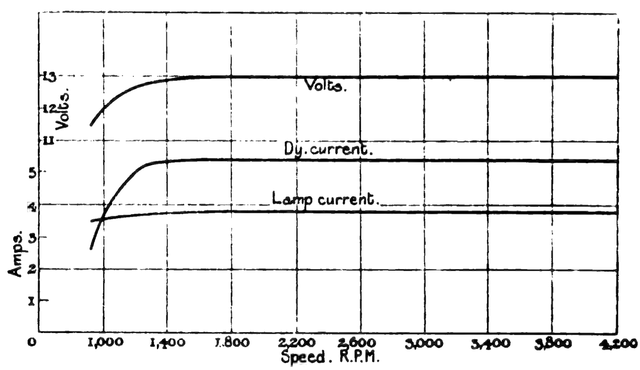


FIG. 13.

on cutting out the head lights (leaving the others in service) the voltage rose to 14. The variation is not serious, but it serves to show that in some degree the governor-controlled clutch possesses the same characteristic as the constant-torque clutch. This difference must be observed however, namely, that by increasing the sensitiveness the speed variation under varying loads can be made much smaller in the governor-controlled clutch than in the constant-torque clutch. It is doubtful, however, whether anything is to be gained by developing the mechanism beyond a certain point, seeing that, even with a perfect mechanism, it is practically impossible completely to avoid variations of voltage with variations of load owing to conditions existing in the dynamo and battery. Such results as those obtained in the tests referred to are sufficiently good for practical purposes. As with other machines, the Lucas dynamo is arranged to work in conjunction with a battery, supplying into the latter about 2 amperes when the maximum

output is reached. When the clutch is adjusted to suit the particular lamps and battery which it is required to supply, the cutting out of the battery involves a large (though restricted) increase of voltage in the lamp circuits. This is, however, not so serious as in the electrically regulated systems described, and would not render it impossible to use the lights in the event of a mishap to the battery.

Much controversy is centred at present on the relative merits of the mechanically and the electrically regulated machines which are capable of complying with service conditions, and this is likely to increase, not because the machines of either system are predominantly superior to those of the other, but because the advantages of each are fairly evenly balanced. It is a significant fact, however, that in spite of the enormous amount of work which has been done in the development of electrical systems of regulation for train lighting, the mechanical systems of regulation appear to be the most extensively used.

Batteries.

Much if not all the variation experienced in the working of the lighting systems above described and not due to speed variation is due to the battery. At different times different voltages are obtained when a machine is run at a given speed. If the battery is fully charged a higher voltage is obtained, and a lower voltage after the battery has been working alone for some time. Different results are also obtained after the battery has been standing for a considerable period, *e.g.*, overnight. Where a moderate current is directed into the battery and the battery is sufficiently large to supply the lamps with current for a lengthy interval without the dynamo, the variations are not large (from 1 to 2 volts), but sufficient to make a noticeable difference in the brightness of the lamps until normal conditions have been regained. This suggests, therefore, that improvements are required in the batteries.

Conclusion.

In conclusion the author desires to express his thanks to the makers who have placed their machines at his service, and also to Mr. Edward C. R. Marks for facilities generously given in carrying out the tests in the Marks and Clerk Laboratory at Birmingham.

Discussion.

Mr. L. Murphy: The author divides the subject into electrically and mechanically regulated devices. Another way, which the makers might not adopt, is to divide them under (1) devices which destroy a battery, and (2) those which heat up a clutch. Many of the devices discussed simply provide means for waste for the surplus energy when the engine is running at speeds just higher than necessary for the generation of the voltage required by the lamps. In one case this Mr. Murphy.

Mr. Murphy.

surplus energy is thrown in the battery, and in the other a clutch wastes energy in the form of heat. An excellent output characteristic is the one shown by the C.A.V. machine, of which the curve in Fig. 8 gave the performance. It will be noticed that in this case the generator output does not increase at any speed to an amount much greater than that required by the lamps. This calls attention in another way to the desirability of not designing a machine for a much greater output than that required by the lamps, but it does not follow that the machine would be small for its work, as this would, of course, result in excessive heating. I do not care for the terms "constant torque" and "constant speed" as applied by the author to these clutches; a more correct way would be to call them "torque-limiting" and "speed-limiting" clutches. With a true constant-speed device there would be no problem at all: we should simply have an ordinary shunt-wound or magneto-dynamo, and leave the constant-speed device to do the rest. I must take exception to the author's condemnation of the magnetic machine on page 754. It is not necessary to design these machines in such a way that they demagnetise themselves at all in use, and if the author's statement were correct such machines could never have found their way to the market. A strong point in favour of the magneto-generator is its comparatively high efficiency for machines of small output. I doubt very much if any of the electrically excited machines described have a full-load efficiency of more than 30–35 per cent., and if the output of the dynamo is, say, 150 watts, this would mean a load of ¾ H.P. on the engine. The great disadvantage of the magneto-generator is, of course, its weight and bulk, but this is probably not insuperable.

Dr. Smith.

Dr. S. P. SMITH: After listening to the author's description of the several electrical and mechanical devices that have been proposed or adopted for obtaining constant pressure for motor-car lighting, one is naturally led to wonder if there is not some simpler method of solving the problem. The trouble seems to arise in the attempt to drive the lighting dynamo from the main engines, the speed of which could not be constant. Surely some attempts must have been made to avoid these complicated contrivances by installing a small auxiliary set for lighting, quite independent of the main engines. The advantages of such an arrangement are at once obvious. Thus there would be a larger amount of freedom in the design of the dynamo and the engine driving, and the set could be made to run at the most economical speed and efficiency. Further, the space taken up by such an auxiliary engine would be very small, owing to the small output required, and since the battery would now be superfluous (except where a reserve was necessary), it is possible that the auxiliary engine might be accommodated in the space thus made free. The efficiency of the dynamo might be considerably improved by using a magneto machine, for the working conditions might, under these circumstances, be suitable for this type. It would be interesting to have the author's opinion on this point, and to hear what experiments have been made in that direction.

Mr. R. V. C. Brook: With regard to the Bleriot system mentioned by the author, which, I believe, was one of the first practical sets on the market, the constant action of the dynamo pumping surplus current into the battery is very detrimental to the latter, and in a case which came under my notice the battery was found to be useless after a short time. With reference to magneto-dynamos, which have been mentioned by previous speakers, I agree with them that it should be possible to produce a machine of this type suitable for car-lighting, which would be more efficient than the self-excited type, and should have a fairly long life, judging from the performance of the modern ignition magneto, which is subject to a rapid-frequency demagnetising action that is absent in the car-lighting magneto. The slipping clutch, which the author said was quite satisfactory, seems to me to be unmechanical, and unless it is looked after it will give trouble owing to the rapid wear. I am of opinion that the problem of regulation should come under the electrical rather than the mechanical head, and I believe that the whole subject is one that large electrical manufacturers, at least in this country, have not gone into deeply; but now that the motor-car is becoming so universal, some of our leading electrical firms might take up the matter, with the result that a sound, simple, and efficient car-lighting set would be produced, which would do away with batteries and other troublesome devices. Mr. Brook.

Mr. R. G. Porte: I do not agree that the battery system is unsuitable, inasmuch as the dynamo has not been sufficiently tested on the heavier type of vehicle. Five years ago I tried a dynamo and found that owing to the excessive vibration to which it was subjected the result was not satisfactory. I therefore adopted the battery and installed sets in 100 of the London-type omnibuses, which in a period of 5 years travelled over 10 million miles. At present there are 150 buses running in London with that system installed. I need hardly state that the batteries are properly looked after, one set being charged while the other set is in use, the discharged battery being taken off at night and a charged one put in ready for the next day's work. The batteries are of Tudor make and are admirably suited to the work. There have been no battery breakdowns, the biggest trouble being lamp renewals. The points to be considered in this class of work are "foolproofness," weight, maintenance, and cost of installation. The cost of the battery system is about one-fourth that of the dynamo system. In the latter system "foolproofness" has not been seriously considered, weight is increased, and the maintenance is, I think, quite as much; but that remains to be seen. I do not wish to convey that I am averse to the dynamo system, as in pleasure cars the system is a boon and works admirably. Mr. Porte.

Mr. M. A. E. L. Moharram: I do not think constant candle-power is really necessary, and consider that the varying speed of the car might be taken advantage of to supply illumination which varies as the speed. If constant illumination is required I would advocate mechanical coupling of the dynamo to the gear-box in such Mr. Moharram.

Mr. Moharram.

a way that varying the gear also adjusted the dynamo speed to suit. I do not allow for fogs, which are not experienced in my country.

Mr. Williamson.

Mr. E. WILLIAMSON: I notice that Mr. Morgan omits all reference to the permanent magnet machine without any regulating field winding, and should like to hear his views on the capabilities of such machines and whether the natural disabilities are sufficiently serious to render them inefficient and unserviceable. It is recognised that the output must vary considerably with varying speeds. Could this objection be sufficiently overcome by the use of extra large accumulators or other simple means?

Mr. Morgan.

Mr. J. D. MORGAN (*in reply*): With reference to Mr. Murphy's humorous suggestion as to the classification of dynamos, it is only necessary to point out that a properly designed electrically regulated machine does not spoil a battery, and a properly designed slipping clutch for mechanical regulation is not subject to serious heating. The suggestion to substitute the terms "torque-limiting" and "speed-limiting" for the terms "constant torque" and "constant speed" devices is good and has been previously considered; but I decided that it was preferable to employ terms which, though they might be slightly inaccurate or not very clear, are in current use amongst those who have to employ the terms. Regarding permanent magnet machines it is very hard to obtain any reliable information, and I have not succeeded in obtaining any machine for testing purposes. It appears to be generally accepted that magnets are subject to rapid weakening of the field, and consequently a machine which when new was constructed to give a certain output at a certain speed would be found to be unable to maintain the output after a short period of use on the road. It might be argued that this has not been experienced with magnetos for igniting purposes, but it must be pointed out that in those machines the maintenance of a constant output is not of serious importance, provided sufficient energy to produce a spark can be obtained, and the field can be weakened considerably without serious result. A slight weakening in a magneto for lighting purposes would probably render it quite useless. It is admitted, however, that magnetos provide a very attractive alternative, and if it is found that they are not subject to deterioration they would be very useful for car-lighting purposes, especially when a speed-controlling clutch was used. Mr. Murphy's suggestion that electrically excited machines have a full-load efficiency of not more than 35 per cent. is inaccurate. With reference to Dr. Smith's suggestion that a small auxiliary set driven from an independent engine might be used for motor-car lighting, this has already been considered in several quarters, and it is felt that eventually the dynamo might probably be driven by a small separate engine. Mr. Moharram's suggestion that a constant brightness of the lamps is not necessary is by no means new, for it has been more than once advocated as a virtue that the lamps increase in brightness with the speed by makers who have tried to make a properly regulated system and failed. A little experience of motoring at night is sufficient

to convince any one that uniform brightness of the lamps is essential. A moment's reflection will show the impracticability of trying to get constant speed in a dynamo by any connection with the ordinary change-speed gear-box. With reference to Mr. Williamson's question as to whether the output from a permanent magnet machine not fitted with any regulating devices could be maintained sufficiently constant by the use of an extra large accumulator, I must say that I have not tried this with permanent magnet machines, but I have tried it on a machine excited from a battery and having an extra large accumulator arranged in parallel with the lighting circuit. It was found that some degree of regulation could be obtained in this way, but it was not sufficiently good for practical purposes. Mr. Morgan.

RECENT DEVELOPMENTS IN STEAM TURBINE PRACTICE.

By K. BAUMANN.

(*Paper received 11th December*, 1911, *received in final form 25th April*, 1912, *and read before the* MANCHESTER LOCAL SECTION *16th January*, 1912.)

CONTENTS.

CONTENTS (*continued*)

INTRODUCTORY REMARKS.

Although the principle of the steam turbine is very old, its application only dates from the introduction of electricity, which made it possible to transmit the power developed by turbines at unavoidably high speeds. This necessitated the development of generators of a special construction, which are known as turbo-generators, in conjunction with the development of steam turbines.

In view of the intimate connection between the two machines, it is essential that the designers of generators should always be informed with regard to the requirements of the turbine designers, and of the future possibilities of turbine development.

Again, electrical engineers in charge of power stations, who form a very large portion of the membership of the Institution, and who are by far the largest purchasers of turbo-electric sets, should be well acquainted with the points which are important for reliable running and economy, and should be kept informed on the main facts with regard to the development of the steam turbine, and the performances obtained on these machines.

For these reasons, this paper, though of a purely mechanical character, may prove of some interest and use to electrical engineers.

I. SUMMARY OF DEVELOPMENTS IN STEAM TURBINES UP TO 1902.

The development of the steam turbine since the first machine was built by Parsons in 1884 may be divided into two periods of a more or less distinct character. During the earlier period, which may be called the invention period, new types of turbines different from those built previously were developed. The distinct types introduced during this period are called according to the name of the inventor, Parsons, de Laval, Curtis, Rateau, or Zoelly turbines, and consist, with the exception of the de Laval turbine, of a certain number of elements

designed on the same principle. For this reason these types are now always referred to as "pure" Parsons turbines, or "pure" Rateau turbines, etc.

The following table gives a summary of the main events during this first period *:—

Parsons Turbines.

Date.

1884. First Parsons turbine built, 10 B.H.P., running at 18,000 revs. per minute, driving direct-current generator.

1888. Parsons reports before the Institution of Mechanical Engineers on a turbine of 50 B.H.P., running at 7,000 revs. per minute, and 200 B.H.P., running at 4,000 revs. per minute.†

1895. Westinghouse Machine Company secures the licence for the manufacture of Parsons turbines in the United States. This was the first licence granted.

1898. First Parsons machine on the market in America.

1898. First Parsons turbine ordered for Elberfeld, Germany—two turbines each of 1,500 H.P., being the largest of their type running up to this time.

1901. Brown-Boveri secures the Parsons licence for the Continent.

de Laval Turbines.

1883. First de Laval turbines with straight nozzles.

1889. First de Laval turbines with divergent nozzles.

1893. de Laval turbines with gears exhibited in Chicago.

Curtis Turbines.

1896. First Curtis patents.

1900. General Electric Company of Connecticut takes up the building of Curtis turbines.

1900. First tests on steam turbines made by the A.E.G. Company.

1904. The A.E.G. Company commence the commercial manufacture of A. E. G.-Curtis turbines on a large scale.

Rateau Turbines.

1894. First tests on steam turbine problems made by Professor Rateau.

1898. First Rateau turbines built by Sautter, Harle & Co., of Paris.

1900. First tests on Rateau steam accumulators.

1902. First commercial use of Rateau accumulators.

Zoelly Turbines.

1903. First commercial Zoelly turbines tested on test-plate.

* C. Matschoss, *Die Entwicklung der Dampfmaschine*, Berlin, 1908, vol. 2, p. 608.

† *Proceedings of the Institution of Mechanical Engineers*, 1888, p. 480.

II. Development of the different Steam Turbine Types since 1902.

During the second period, which may be called the development period, the design of the steam turbine has been perfected on the basis of the experience gained on the existing turbines and of experimental research work founded on the theory of steam turbines. This was made possible to a very great extent by the fundamental work of Professor Stodola, whose book on steam turbines, of which the fourth edition was issued last year, must be considered as the standard book of the design of steam turbines. This book originated in a paper read by Professor Stodola before the Verein Deutscher Ingenieure at Dusseldorf in 1902,* which date may be taken as the beginning of the second period of turbine development.

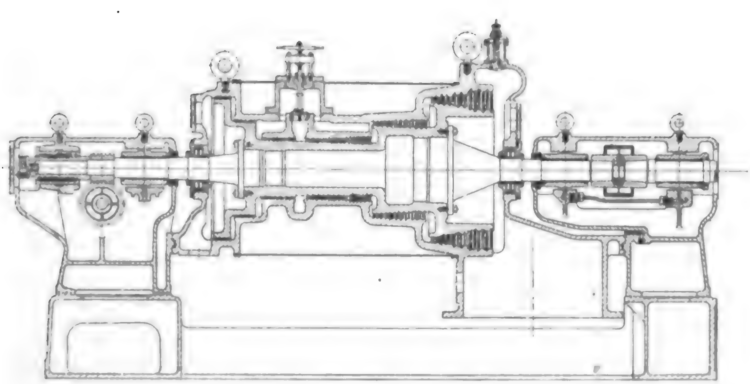


Fig. 1.—Parsons Turbine.

During this period not only were great improvements made in the design of the various pure types, referred to above, but further advantages were gained by combining these types in such a manner as to obtain the best results, both with regard to reliability, efficiency, and cost.

In order to follow this development clearly, it is necessary to consider the advantages and disadvantages of the different types. These are dealt with below in the following order:—

1. Parsons turbine.
2. Curtis turbine.
3. Rateau and Zoelly turbines.

The de Laval turbine has been excluded from the descriptions, as owing to its design it can only be used for small powers, and it has been developed to the highest degree of perfection by the inventor, de Laval

* *Zeitschrift des Vereines deutscher Ingenieure*, vol. 47, p. 1, 1903.

himself. de Laval's work in this connection, in overcoming difficulties of an absolutely novel character, which involved the origination of quite new methods, has proved him to be one of the master minds in engineering.

1. *Development of the Parsons Turbine.*—The Parsons turbine (Fig. 1) is a multi-stage reaction turbine of the drum type, running at a moderate peripheral velocity. The fact that until very recently it has been built upon exactly the same principles as the first turbine in 1884, and that it has competed very successfully even with the newest types, reflects the

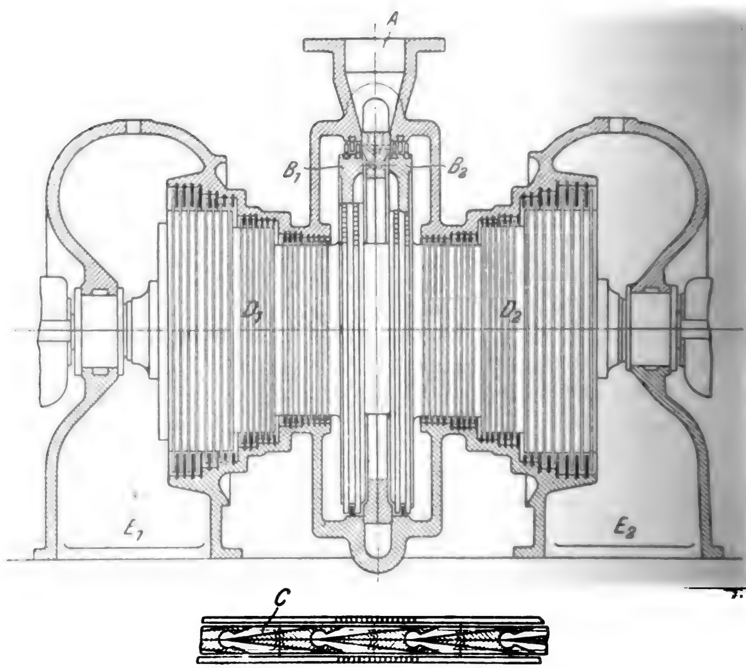


FIG. 2.—Westinghouse Double-flow Turbine (Patent Drawing, 1904).

greatest credit on its inventor, to whom, as the originator of steam turbines, we all pay our tribute.

The pure Parsons turbine has the great advantage of a moderate peripheral velocity which allows a very simple design of fixing the blading. This, in addition to the relatively small drum and cylinder diameters, enables this type of turbine to be manufactured at a considerably lower cost than steam turbines with discs and diaphragms.

One of the main disadvantages of the Parsons turbine is that the high-pressure part of the cylinder is subjected to the highest steam pressure

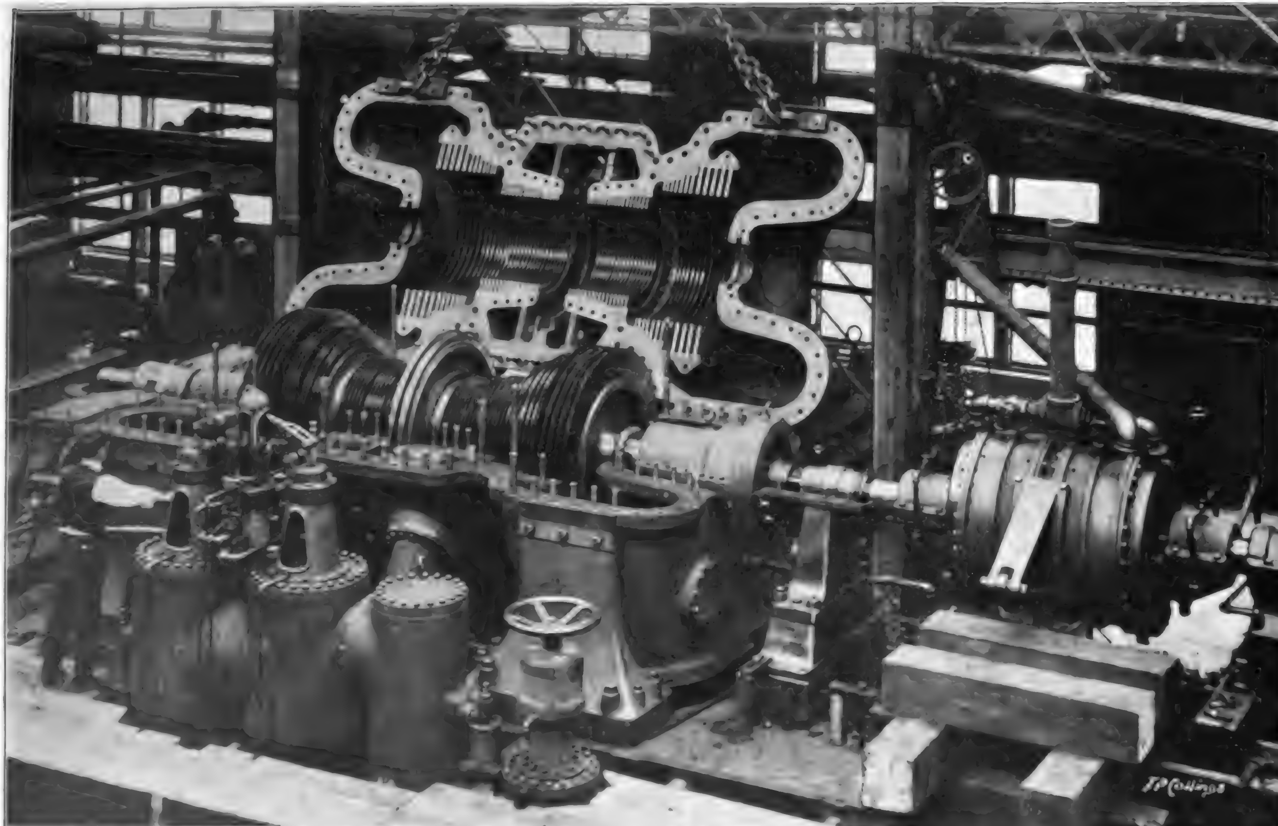


FIG. 3.—Modern Westinghouse Double-flow Turbine, 1909.

and superheat, which becomes more accentuated by the necessity of small clearances in that part and by the growth of cast iron after repeated heating.* A further disadvantage is the use of balance pistons with very small clearances.

The first attempts to overcome these difficulties were made by George Westinghouse,† who replaced the high-pressure stages by a Curtis wheel and overcame the difficulty of the balance piston by using the double-flow arrangement, which had already been used by Parsons on his first turbine in 1884. Fig. 2 gives Westinghouse's patent drawing.‡

This arrangement, which practically means the use of two separate turbines, is too expensive for small units and is therefore only applied for large outputs. The duplication of the velocity wheel, shown in the

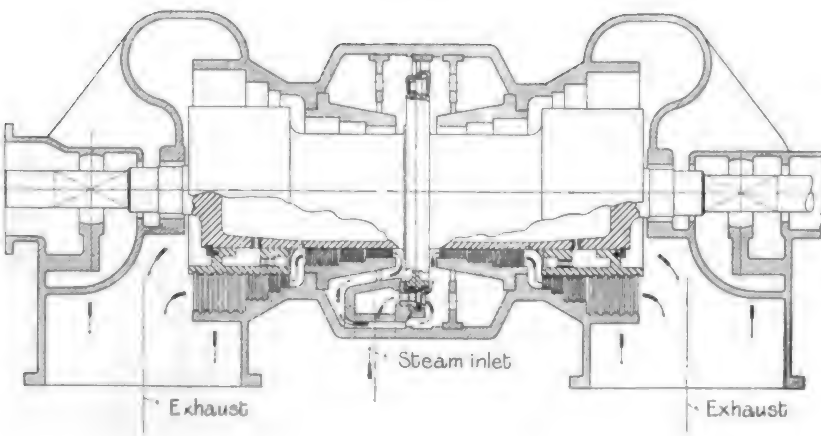


FIG. 3A.

drawing, is of course not necessary, as the pressure in front and after the wheel is the same, and a special arrangement for balancing this part is therefore unnecessary. A modern design of such a turbine is shown in Figs. 3 and 3A, which represent a section and a view of a 15,000-k.w. maximum-rated double-flow turbine, running at 1,800 revs. per minute, which was supplied to the City Electric Company, San Francisco, in 1909.

For smaller outputs, the American and British Westinghouse Companies developed in 1906 the type shown in Fig. 4, which may be called a combined disc and drum single-flow double-flow turbine. The high-pressure part consists of one velocity wheel and one Parsons drum, and the low-pressure part consists of two drums through which

* See Professor Carpenter's investigations on this subject.

† *Power*, 1904, p. 265.

‡ Swiss Patent No. 28566, also United States Patent No. 787485, patent applied for 1903, patented 1905.

the steam is flowing in opposite directions. This arrangement necessitates, however, a dummy piston in the centre of the turbine, and therefore cannot be considered as a very perfect solution of the problem.

For small outputs, where a double-flow turbine is too expensive, the British Westinghouse Company developed in the year 1905 a type shown in Fig. 5, which is known as the single-flow disc and drum turbine, consisting of one Curtis wheel in the high-pressure part of the turbine and a Parsons drum of uniform diameter in the low-pressure part with corresponding balance piston on the high-pressure end.

One of the first firms to replace the high-pressure part of the Parsons turbine by velocity wheels was Messrs. Sulzer Bros. The first turbine manufactured in 1904 * (Fig. 6) consisted of two Curtis wheels

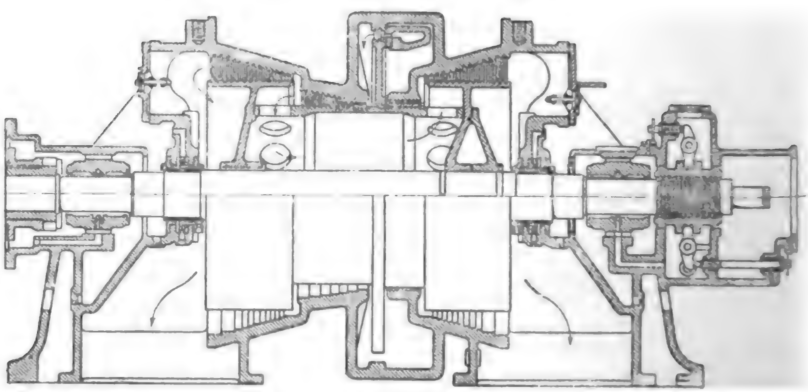


FIG. 4.—Combined Disc and Drum Single-flow Double-flow Turbine. Westinghouse Company's, 1906.

in the high-pressure part and two single-flow Parsons drums. The difficulty with regard to the balance piston was overcome by causing the steam to flow through the medium-pressure Parsons drum, in the opposite direction to that through the low-pressure drum. This arrangement necessitates diaphragms with glands in the centre of the turbine and a passage in the cylinder to pass the steam from one end of the turbine back to the centre of the turbine.

For the newer design (Fig. 7), the straight single-flow type † has been used, with one velocity wheel with three rows of blades in the high-pressure part in order to reduce the pressure in the turbine as much as possible (to about 1·5 atmosphere absolute) and three single-flow Parsons drums with increasing diameter towards the low-pressure end of the turbine. The thrust of the Parsons drum is balanced by an automatic oil piston in connection with a thrust bearing, which forms

* A. Stodola, "Steam Turbines," 3rd ed., p. 313.
† Ibid., 4th ed., p. 468.

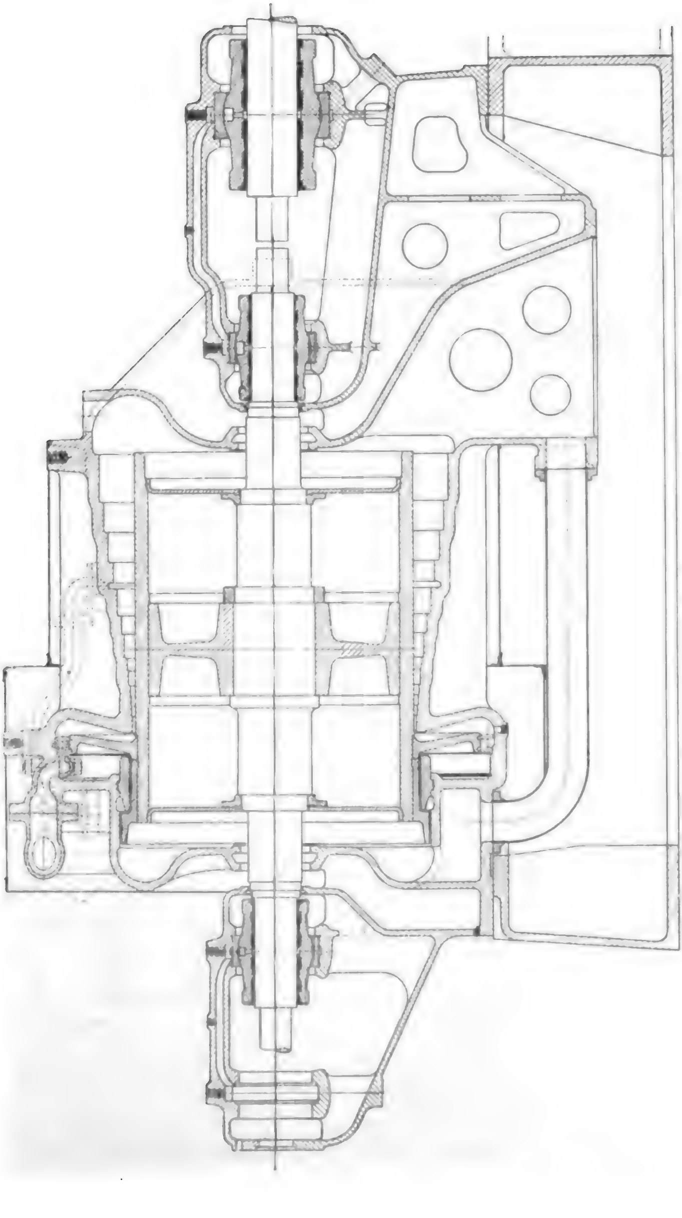


Fig. 5.—Westinghouse Single-flow Turbine. The British Westinghouse Company, 1905.

one of the greatest novelties in steam turbine design. Another feature of their newest designs is the governing of the turbine by oil pressure at the discharge side of a centrifugal pump, without the use of a mechanical governor.*

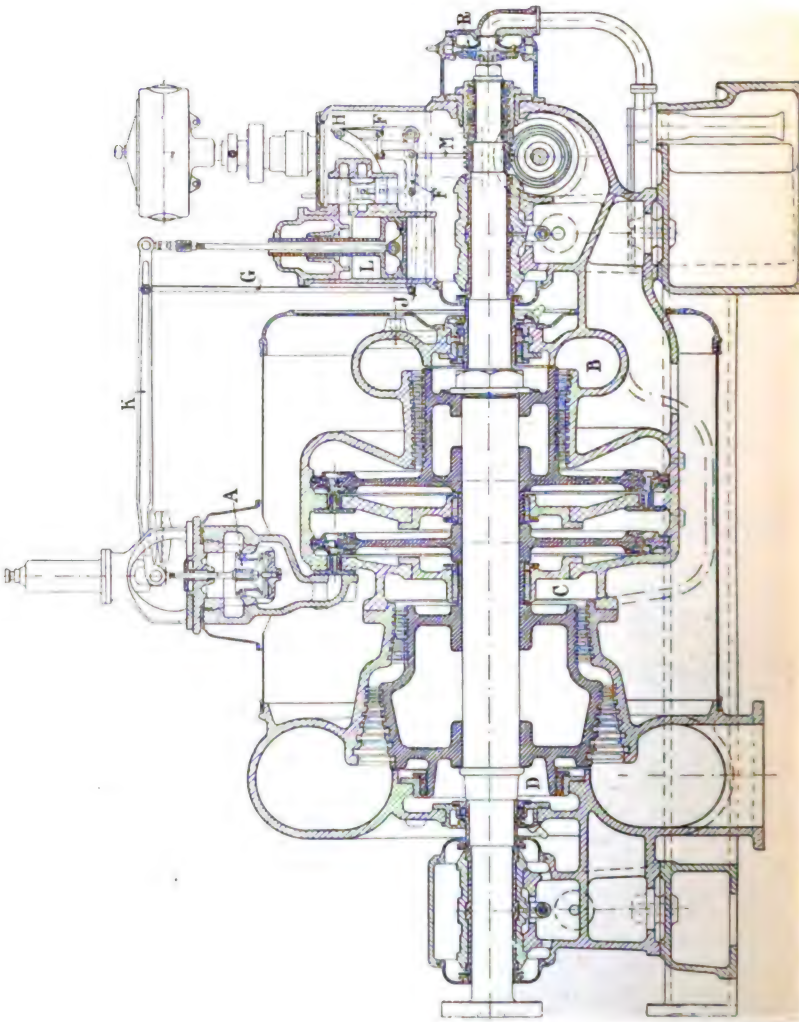


FIG. 6.—Sulzer Turbine, 1904.

The attitude of the various firms building the "pure" Parsons turbines towards the development of the combined Curtis-Parsons type was followed with the greatest interest in engineering circles. A

* A. Stodola, *Zeitschrift des Vereines deutscher Ingenieure*, vol. 55, p. 1709. 1911.

report of tests which had been made on a combined turbine of 1,000 k.w. at 3,000 revs. per minute manufactured by Brown-Boveri,

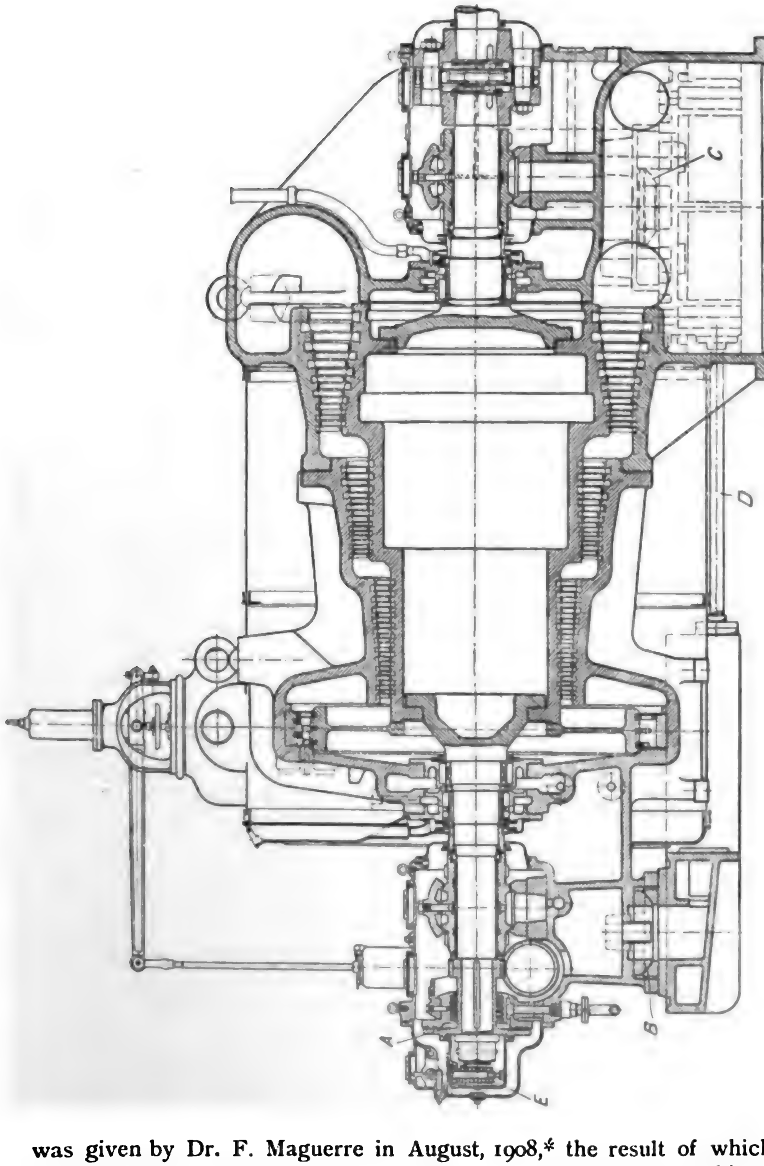


FIG. 7.—Sulzer Turbine, 1906.

was given by Dr. F. Maguerre in August, 1908,* the result of which was summed up as follows: "There are cases where a combined

* *Zeitschrift des Vereines deutscher Ingenieure*, vol. 52, p. 1346, 1908.

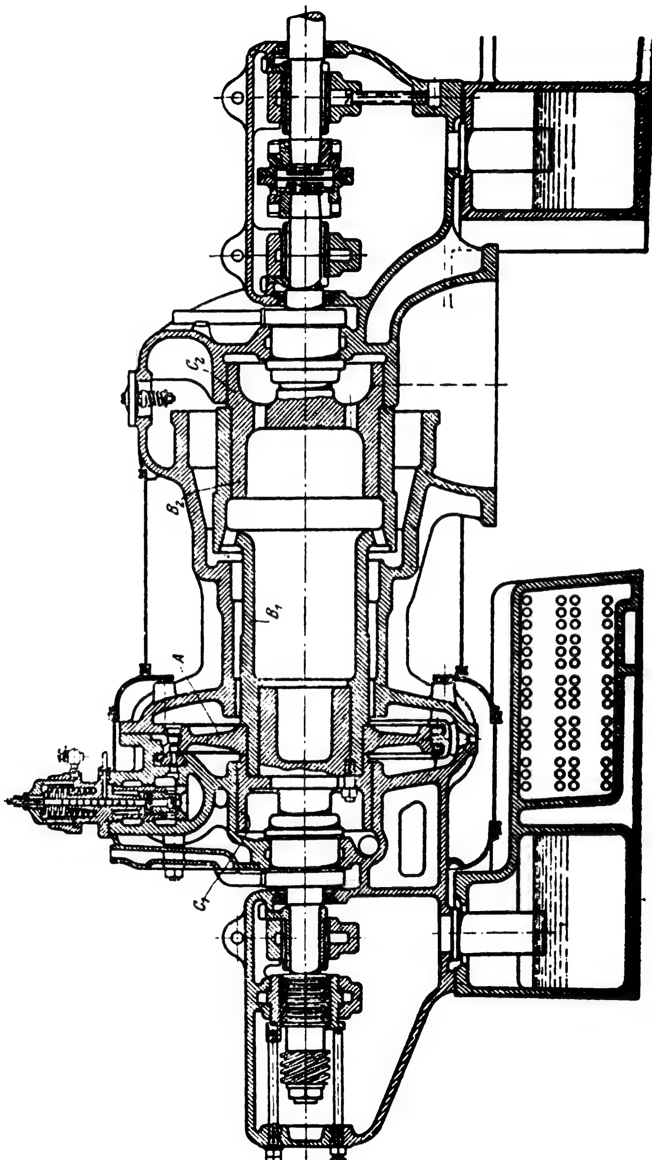


FIG. 8.—Brown-Boveri Turbine, 1908.

turbine may be of great interest, but in most of the cases the pure Parsons turbine will be superior to the combined turbine with regard to steam consumption and reliability, but not with regard to space required, which condition is, however, of little importance."

Dr. Maguerre claimed that a pure Parsons turbine for that output would be much more efficient, and that a combined Curtis-Parsons turbine would only be equal to a pure Parsons turbine for normal outputs below 500 k.w., but that disadvantages with regard to wearing and pitting of the blades would not justify the application of the combined type.

A few months afterwards it was common knowledge that Brown-Boveri had taken up the manufacture of the combined type for smaller outputs. Their design is shown in Fig. 8, which at the present time is made by nearly all manufacturers of Parsons turbines and for all outputs.

This fact can only show that the improvements made in the later designs of the Curtis wheel justified its use, and the competition with other firms forced the manufacturers of pure Parsons turbines to adopt it. The new design, shown in Fig. 8, still retains the use of the balance piston, which, however, becomes much simpler than that on pure Parsons turbines, when used according to Fullagar's patents. The balance piston must, however, still be considered as the weak point of the turbine, and the future will have to decide which of the two methods of balancing is superior—by dummy pistons, or by oil pistons as proposed by Sulzer Bros.

2. *Development of the Curtis Turbine.*—The first Curtis patents, dated 1896, refer to turbines of the impulse type consisting of a number of single Laval wheels arranged in series. Curtis did not consider this arrangement to be the best means of reducing the speed of a steam turbine, and he therefore introduced with success the velocity stages which were already described in English Patent No. 144, dated 1858, by John and Ezra Harthan.* The pressure stages were reduced and the correspondingly high steam velocity utilised in wheels with several rows of blades on the velocity stage principle. These wheels are known as Curtis wheels or velocity wheels.

The first turbines, built by the General Electric Company of Schenectady, who secured the licence for the Curtis patents, consisted of only two pressure stages and two wheels each with four rows of blades; afterwards these were changed, on account of poor efficiency, to four pressure stages and four wheels, each with only two rows of blades (Fig. 9). The General Electric Company always built their turbines with vertical shaft, in order to reduce the floor space required. The steam entered the turbine at the top end through nozzles to which the steam was admitted by separately controlled valves opened one after the other according to the load. The General Electric Company were the originators of the nozzle controlled turbines.

In order to understand clearly the further development, it is neces-

* A. Stodola, "Steam Turbine," 4th ed., p. 637.

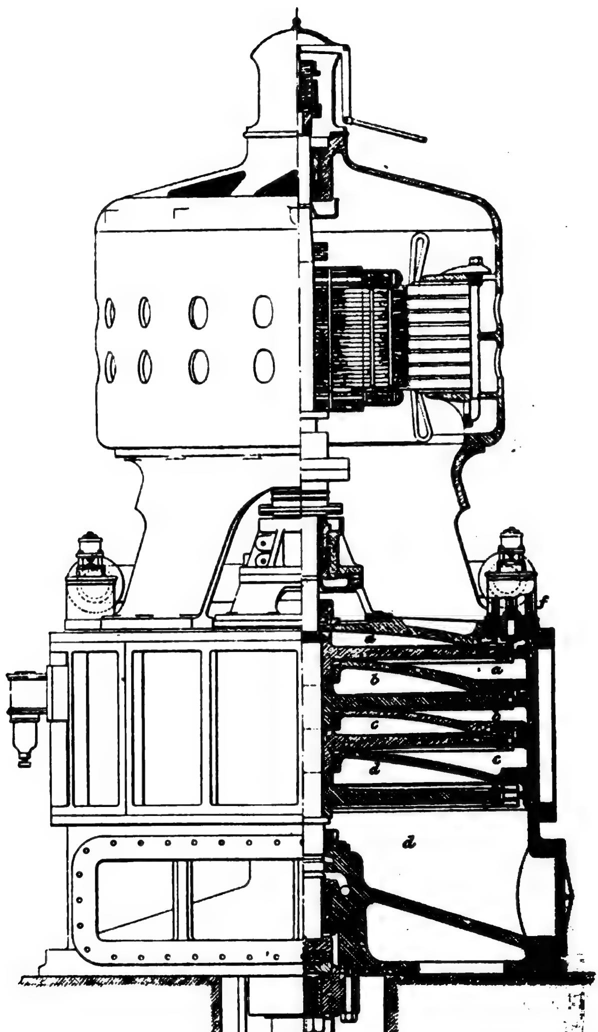


FIG. 9.—Vertical Curtis Turbine (about 1902).

sary to compare the efficiencies which can be obtained with the Curtis wheels, having two or three rows of blades, with those obtainable with single wheels of the de Laval type.

Let—

u = mean peripheral velocity of blades.
c = steam velocity corresponding to pressure drop.
η = blading efficiency.

If steam is admitted to a wheel with one row of blades at a certain velocity c and the wheel is revolving at different speeds u, calculation shows that the efficiency is at a maximum for a certain peripheral velocity, which is given by the ratio :—

$$\frac{u}{c} = \frac{\text{peripheral velocity}}{\text{steam velocity}} = \tfrac{1}{2}.$$

For any other ratios $\frac{u}{c}$ the efficiency will be smaller and changes according to curve A, Fig. 10, which is of a parabolic nature. It will be zero when $u = 0$, as in this case no work can be done, and also when $u = c$, as in this case the torque will be very small.

The actual maximum efficiency and the ratio $\frac{u}{c}$ at which it is obtained depends mainly on the inlet angle and the ventilation losses of the wheel. Curve A in Fig. 10 represents a fair average of test results actually being obtained in the low-pressure part of modern Rateau turbines. The maximum efficiency according to this curve is :—

$$80 \text{ per cent. for } \frac{u}{c} = 0{\cdot}46.$$

The average efficiency of high-pressure and low-pressure wheels of a Rateau turbine, designed for maximum efficiency, will be about 77 per cent., allowing for increased friction and leakage losses in the high-pressure part of the turbine.

For velocity wheels with two rows of moving blades the efficiency changes in quite a similar manner, the only difference being that the maximum efficiency is reached for $\frac{u}{c} = \frac{1}{4}$ approximately. The efficiencies which can be obtained are given by curve B in Fig. 10, which shows a maximum efficiency of 67·5 per cent. at $\frac{u}{c} = 0{\cdot}23$.

For velocity wheels with three, four, or five rows of blades the maximum efficiency is obtained for $\frac{u}{c}$ less than $\frac{1}{6}, \frac{1}{8}, \frac{1}{10}$ respectively. Of these, however, only the velocity wheel with three rows of blades is of practical importance. The actual efficiencies obtainable are given by curve C, Fig. 10, which shows a maximum efficiency of only 52·5 per cent. for $\frac{u}{c} = 0{\cdot}133$. The efficiencies of velocity wheels with more

than three rows are still worse, and they are therefore not used except in cases of marine turbines.

According to diagram Fig. 10, it is obvious that with different wheels of the same diameter, running at the same peripheral velocity, the wheel which has two rows of blades will be able to utilise, at its best efficiency, a steam velocity twice as high as that for a wheel with one row of blades; a wheel with three rows of blades will utilise a velocity about 3·46 times as high as that for which the efficiency

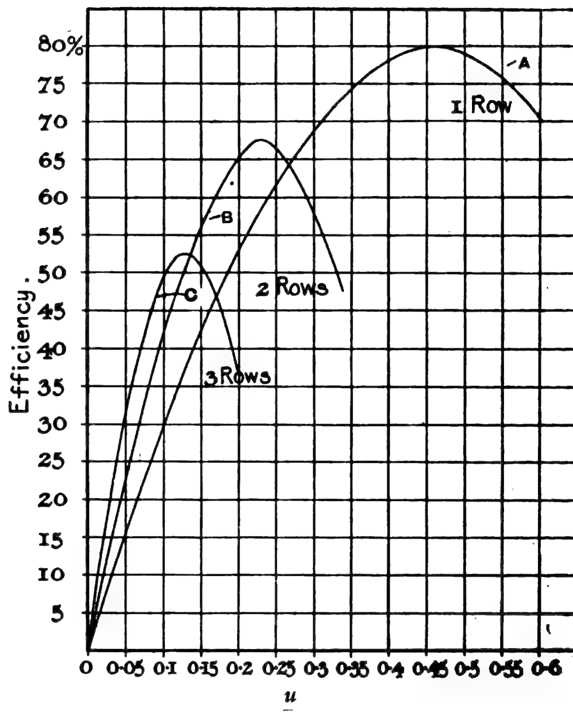


FIG. 10.—Efficiencies of Rateau and Curtis Wheels.

of a wheel with a single row is a maximum. As the heat energy increases with the square of the steam velocity, this means that turbines designed to utilise the same heat drop with the best efficiency obtainable with the different kind of wheels must have—

1 wheel with 3 rows of blades, maximum efficiency being 52·5 per cent; or—

3 wheels with 2 rows of blades, maximum efficiency being 67·5 per cent; or—

12 wheels with 1 row of blades, maximum efficiency being 77 per cent.

When the A.E.G. Company took up the building of Curtis turbines they had to consider these facts, as it was of the greatest importance to them to have a turbine able to compete in economy with the Parsons turbines, which latter turbines up to the year 1905 undoubtedly held the field.

The higher cost of coal in Germany, as compared with America, necessitated the use of more economical turbines than the pure Curtis machines built in America by the General Electric Company.

The pure Curtis turbine has the great advantage of small pressures and low temperatures in the turbine casing, due to the relatively great expansion through the first nozzles, an advantage which the designer of a Continental Curtis turbine could not dispense with. The Curtis wheels in the low-pressure end, which, according to the table given above, cannot give as good efficiencies as single wheels, were replaced by the more expensive Rateau wheels, in order to obtain a turbine with a competitive efficiency.

The result was the turbine shown in Fig. 11, of which the first reports were given by O. Lasche in a paper read before the annual meeting of the Verein deutscher Ingenieure in 1906.*

The turbine is, in addition, built with a horizontal shaft which very recently has also been adopted by the General Electric Company in America. Though at first sight it is differently built from the pure Curtis turbine, there is still quite a noticeable resemblance to the original machine in some of the parts which are peculiar to the A.E.G. turbines.

The predominating part is still the velocity wheel, which is made of a larger diameter than the Rateau wheel in order to reduce the pressure in the turbine casing as much as possible. The cylinder is divided at the high-pressure end of the turbine by a vertical joint. The high-pressure end cover is generally made of cast steel and in one piece, in the same manner as the original Curtis turbine. This is obviously necessary because the high-pressure pedestals are fixed on this cover; if this cover were made in halves unsymmetrical deflection of the cover would occur, and this would throw the bearing out of line. The design of the diaphragms is also similar to that of the original Curtis turbine. They are made in one piece, and must be assembled on the shaft at the same time as the wheels. This arrangement makes erection rather difficult and reduces the accessibility of the shaft to a great extent.

Another feature of the A.E.G. turbine is the arrangement of the turbine and generator shafts and the bearings, known as the three-bearing design, which is also identical with the design of the Curtis turbine. One of the first turbines of this design, of 3,000-k.w. normal output, running at 1,500 revs. per minute, installed at Moabit in Berlin, was reported in March, 1907,† to use only 12·8 lbs. of steam per kilowatt-hour, and a similar turbine of 4,000-k.w. normal output at

* *Zeitschrift des Vereines deutscher Ingenieure*, vol. 52, p. 1289, 1908.

† O. Lasche, *Zeitschrift des Vereines deutscher Ingenieure*, vol. 51, p. 385, 1907

1,500 revs. per minute, installed at Rummelsburg, near Berlin, was reported in April, 1909,* to have a steam consumption of only 11·7–11·95 lbs. per hour. Both figures were the lowest figures recorded at the respective times.

3. *Development of Rateau and Zoelly Turbines.*—The principle of the Rateau or Zoelly turbine is very old. In 1827 Real and Pichon took out French patents for a similar turbine with 31 wheels.† Another patent for a similar turbine was taken out in England in 1876 by Edwards as a communication from James Mourhouse, of Petersburg (Patent No. 2068/1876). This turbine was also of the impulse type, and was provided with 25 wheels. The drawing showed already

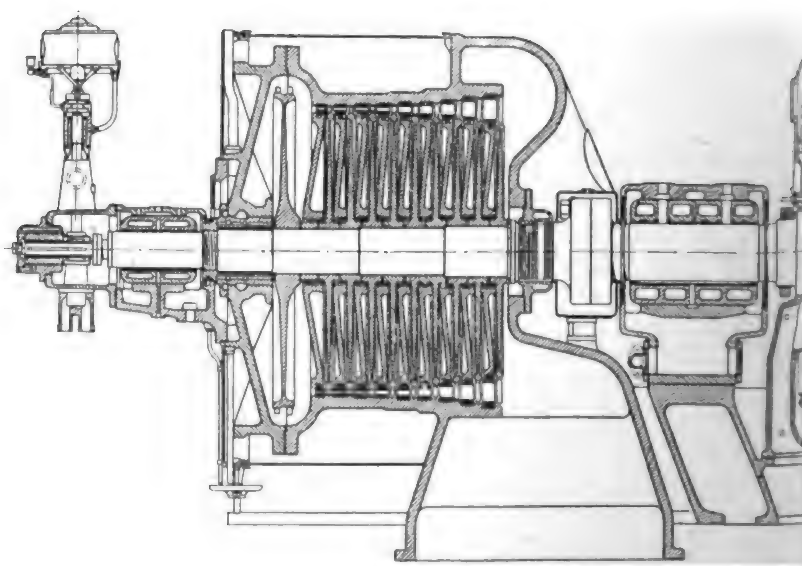


FIG. 11.—A.E.G. Turbine, 1906.

increasing area through the nozzles, in order to allow for the increased volume due to the expansion of the steam.

The credit for the further development of this type must, however, be given to Professor Rateau. The first turbine which was built by Professor Rateau in 1898, in conjunction with the engineering firm of Sautter Harle & Co., of Paris, consisted of only one wheel running at a very high peripheral velocity. This design, however, was found to be too expensive, and the next turbine was made as a multistage turbine, which consisted of a series of discs rotating between diaphragms, in accordance with Professor Rateau's patents (English

* O. Lasche, *Zeitschrift des Vereines deutscher Ingenieure*, vol. 53, p, 684, 1909.
† See Hofweber, *Zeitschrift des Vereines deutscher Ingenieure*, vol. 51, p. 1318, 1907.

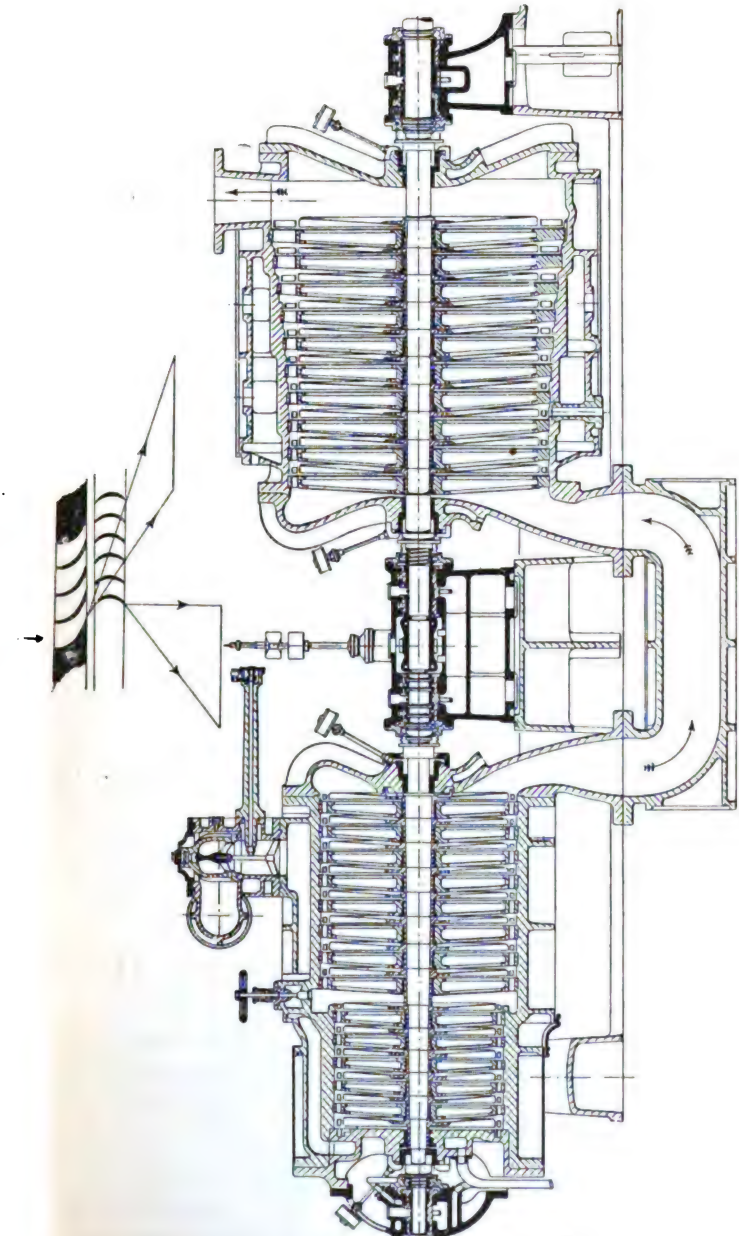


FIG. 12.—Rateau Turbine, built by Sautter Harlé, 1902.

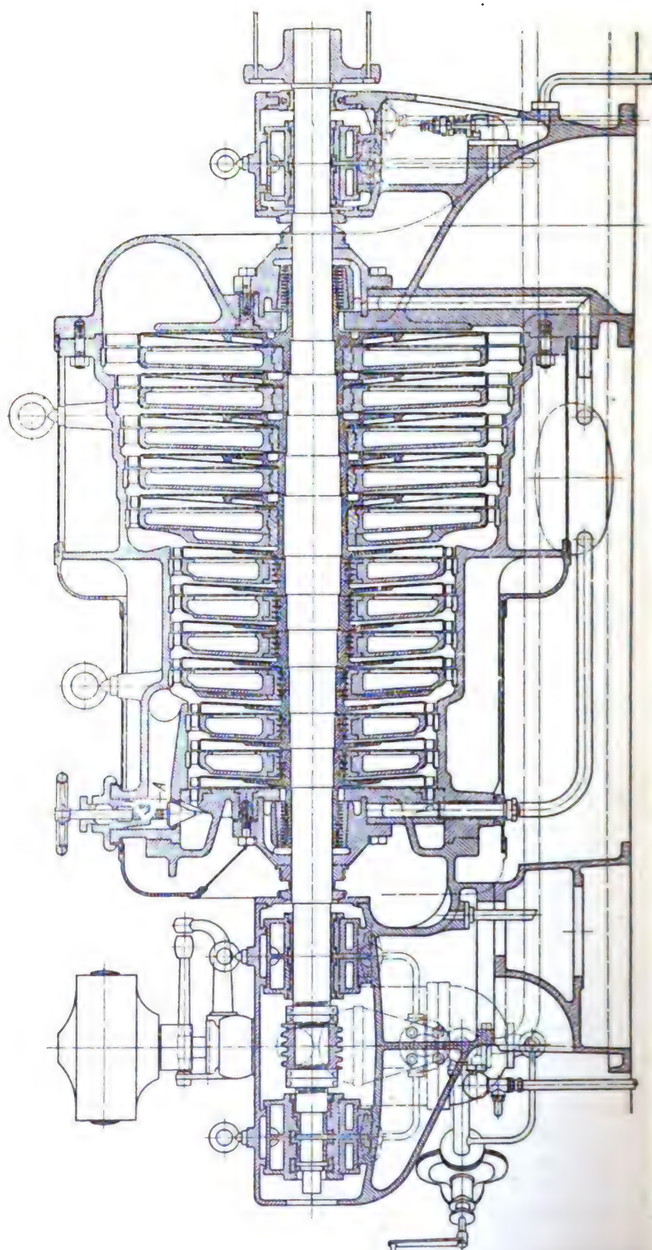


FIG. 13.—Rateau Turbine, built by Engine Works, Oerlikon, 1903.

Patent 24204/1898). One of the first turbines of this type actually built consisted of 25 wheels in two casings shown in Fig. 12. The peripheral velocity was kept rather low, in order that built-up wheels consisting of boiler plates riveted to a boss on the shaft could be used, which at that time were cheaper than forged wheels. Soon afterwards this type of turbine was made with a smaller number of wheels in one casing by the Engineering Works, Oerlikon (Fig. 13).

The Zoelly turbine, of which the first machine was made in 1903, was similar to the Rateau turbine, the only exception being that the number of wheels were considerably reduced. The wheels were made out of forged steel, and this enabled the designers of the Zoelly turbines to increase the peripheral speed considerably, and at the same time to decrease the number of wheels. The first Zoelly turbine (Fig. 14) consisted of 12 wheels in two casings, in a similar manner to the Rateau turbine shown in Fig. 12. The patents of Zoelly refer to a particular method of fixing the blades on a rotating disc. Another peculiarity of the first Zoelly turbines was the open blade without shrouding. The reduction in the number of wheels was proved to be a great advantage, and this, together with the care exercised in the design of the detail parts which were partly taken from the water turbines—*e.g.*, the governor with oil relay—caused a very rapid commercial development of the Zoelly turbine.

The design in which two casings were used was soon abandoned for one with a single casing. A turbine of this type, made in 1907 for the Elektrizitatswerk, in Kubel, near St. Gall, is shown in Fig. 15.

Both Zoelly and Rateau used smaller diameters for the high-pressure wheels and large diameters for the low-pressure wheels, in order to keep the disc friction and ventilation losses of the high-pressure wheels as small as possible. On the other hand, this increased the number of stages, and consequently lengthened the turbine—it further involved the introduction of high pressures and high temperatures in the turbine casing, the danger of which was not fully realised at that time. It was also usual on these turbines to have the shaft running above the critical speed, so that when starting up, the turbine had to pass through the first critical speed. The experience gained in the running of this design of turbine emphasised these disadvantages, and forced the builders of the Rateau and Zoelly turbines to change their designs and adopt the same diameter of wheel all through the turbine in order to reduce their number and to shorten the machine. In addition, the pressure drop through the first nozzles was increased in order to decrease the pressure and temperature in the turbine casing. The sacrifice in the efficiency of the high-pressure wheels was balanced as far as possible by the improved efficiency obtained on the low-pressure wheels. These alterations were made at the same time by Zoelly and Rateau in 1908, and proved to be a great advance.

The new Zoelly turbine is shown in Fig. 16, and a Rateau turbine in Fig. 17. It will be noted that in principle there is no great difference

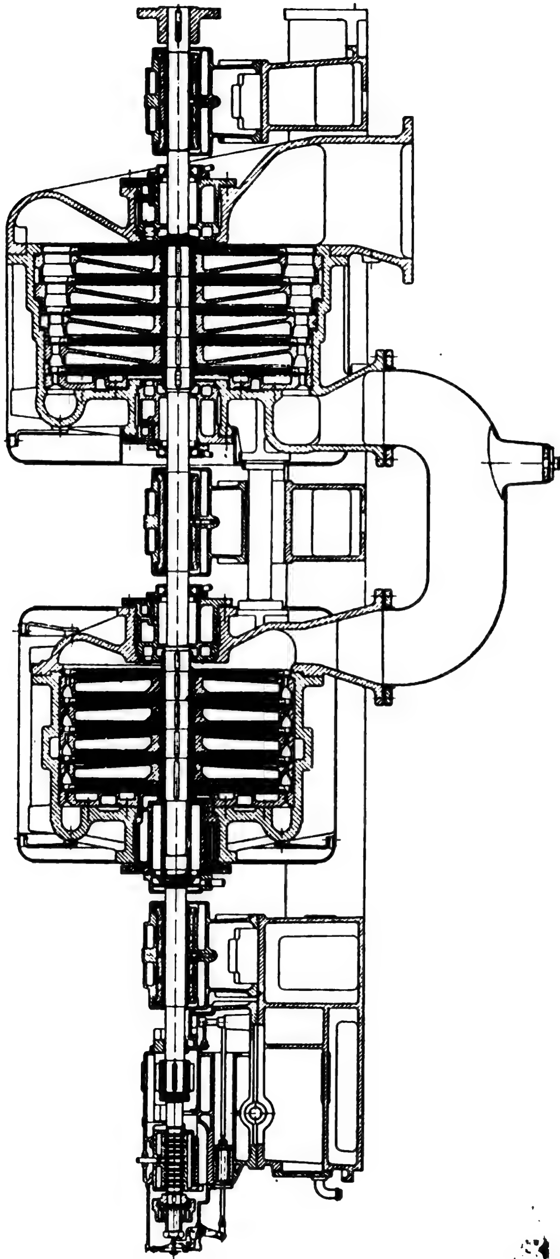


FIG. 14.—Zoelly Turbine, 1903.

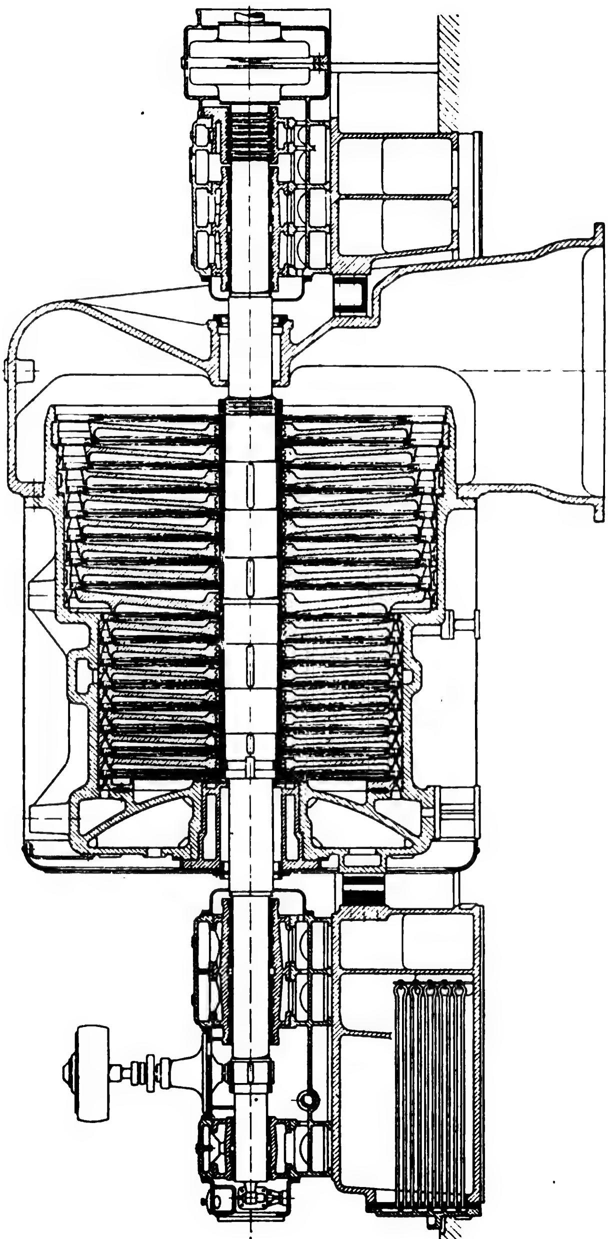


Fig. 15.—Zoelly Turbine, 1907.

between the Zoelly turbine and the Rateau turbine. In the meantime, owing to the rapid development of the disc turbines, the steel manufacturers had obtained great experience in the making of discs, and this enabled them to reduce the cost considerably. This caused Professor Rateau to revert to the forged discs originally used, and this enabled him to increase the peripheral velocity of the blades. Open blades as used on the first Zoelly turbines were abandoned for the newer design with shrouding, which increased the efficiency considerably.

It was obvious that by replacing the first single wheels by a velocity wheel, the pressures and temperatures could still further be decreased. The Maschinenfabrik Augsburg-Nürnberg was the first of the Zoelly

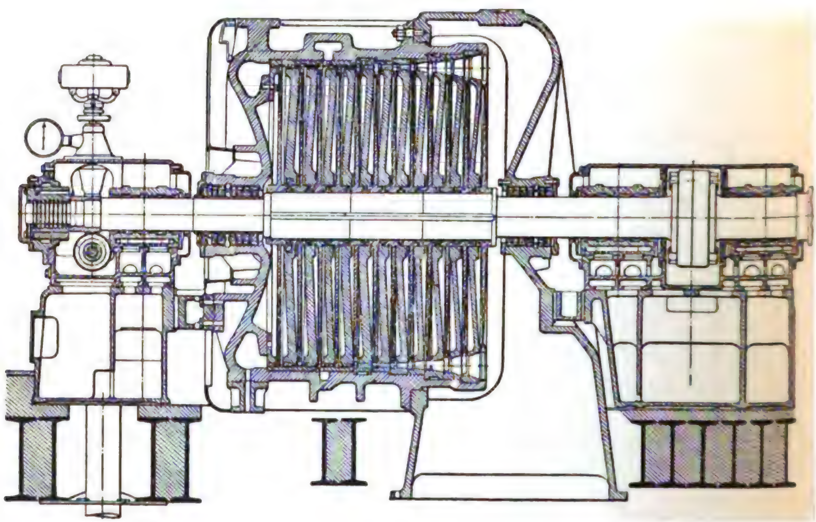


FIG. 16.—Modern Zoelly Turbine, 1908.

turbine builders to replace the high-pressure wheels by a velocity wheel (1909), as a result of extensive tests on velocity wheels and also on combined turbines. These tests showed that the efficiency of a correctly designed velocity wheel compared very favourably with the efficiency obtainable with the first Rateau high-pressure wheels of the new design.

When the British Westinghouse Company commenced in 1908 the building of Rateau turbines, it had the benefit of experience gained in the building of Parsons turbines, which had resulted in the use of velocity stages in the high-pressure end. One of the first Rateau turbines built by the Westinghouse Company is shown in Fig. 18, which represents a section of a 5,000-k.w. turbine running at only 750 revs. per minute, supplied to the London County Council power station, Greenwich. This turbine, on account of the very low speed,

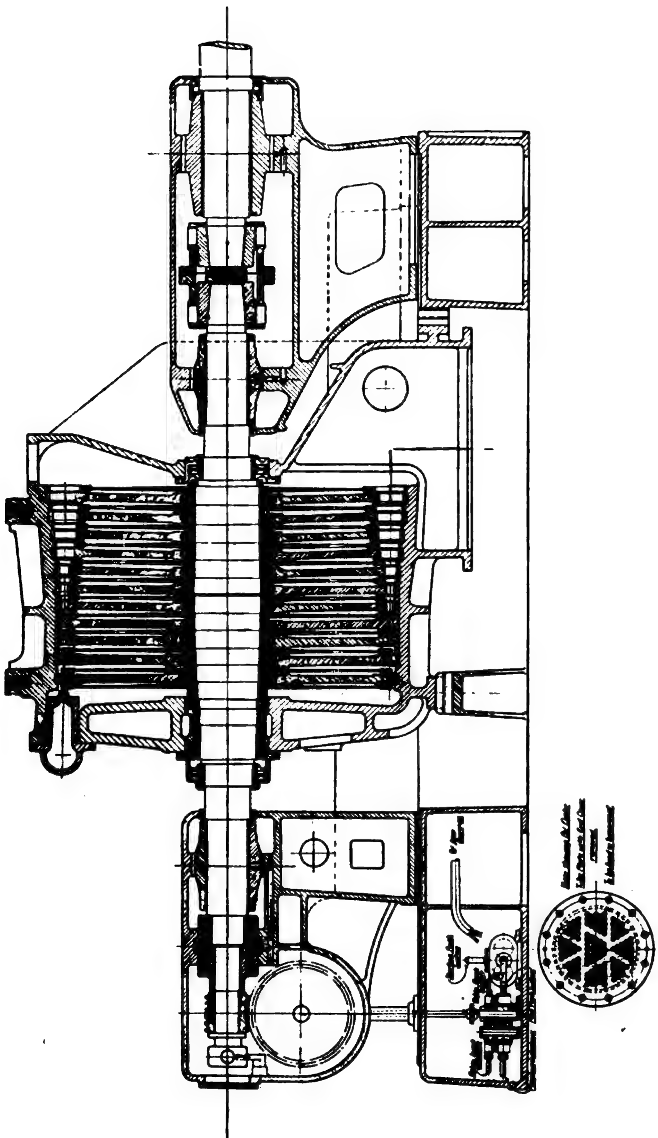


FIG. 17.—Modern Rateau Turbine, 1908.

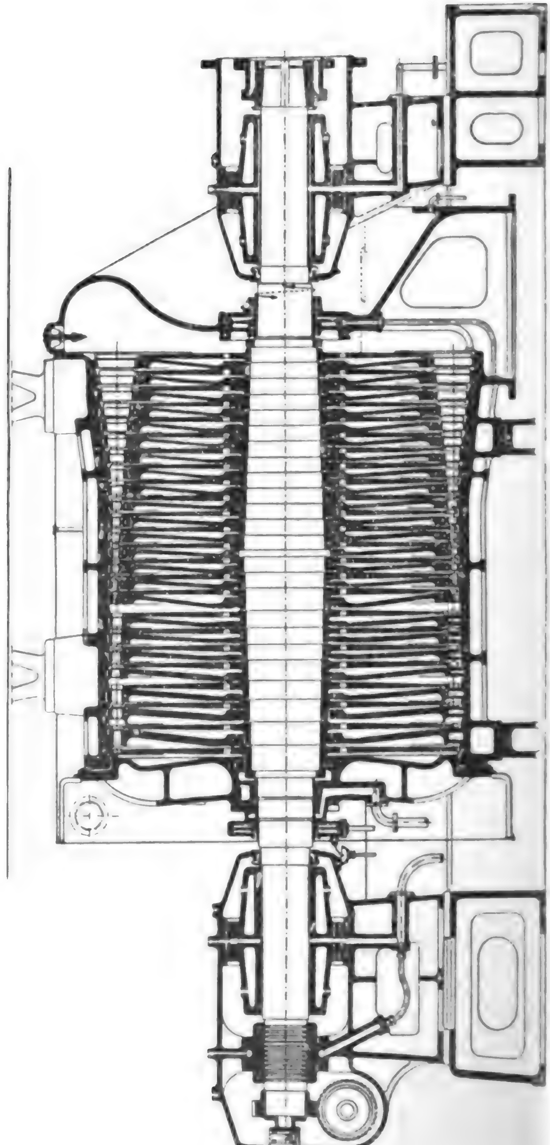


FIG. 18.—Rateau Turbine built by the British Westinghouse Company, 1909.

had to be provided with 24 wheels. The type of Rateau turbines built since 1909 is shown in Fig. 19.* The steam is admitted to the velocity wheel through nozzles fixed to nozzle boxes of cast steel, and which, with the steam chest, are the only parts of the turbine subject to high pressures, and high temperatures. The design of the casing and the diaphragms, which are both made in halves with only horizontal joints, allows of a very easy inspection and accessibility to the rotor, and to the interior of the turbine by lifting the top half. Due to the use of a velocity wheel the gland question which, during the whole development of the steam turbine was a very important one, becomes much simpler.

In the case of a pure Rateau or Zoelly turbine, the glands have to be made reasonably tight against high pressures. In the earlier designs they were made of loose metal packing rings, and according to the latest practice with loose carbon rings. When using a velocity wheel an ordinary labyrinth gland has proved to be quite satisfactory with regard to the leakage of steam, and has the advantage of greatest simplicity and reliability. The high-pressure gland is connected to the exhaust of the turbine and is sealed against air by the well-known water gland used on the Westinghouse Parsons turbines, which is also retained as a low-pressure gland.

III. Comparison of the Modern Turbines.

The recent development of the various steam turbines outlined above shows very clearly the tendency towards the use of the two types known as the disc and drum or the Curtis-Parsons type and the Curtis-Rateau type.

These must be considered the most important type at present in use, as is best shown by the fact that practically all turbine builders in this country are adopting one or the other, and it will therefore be interesting to examine closely the points of difference between them. To do this it is necessary to consider the two types with regard to reliability, economy, and first cost. This examination will show that it is not possible to give a definite statement, that in general one is better than the other, but this depends on the particular conditions under which the turbine is required to work in any particular case.

The reliability of the turbine will depend much more on the design of its details than on the principle on which it is constructed. It is quite certain that the design of the fixing of the blades, for instance, which does not depend on the type of the turbine, is of great importance. But it is also evident that a turbine with very small clearances between fixed parts and parts running at a relatively high velocity will not be so reliable as a turbine with large clearances between these parts.

With regard to the other points—*i.e.*, economy and first cost—we will limit our comparison to the high-pressure turbine, which is mainly used in power stations.

* *Engineering*, vol. 91, p. 41, 1911.

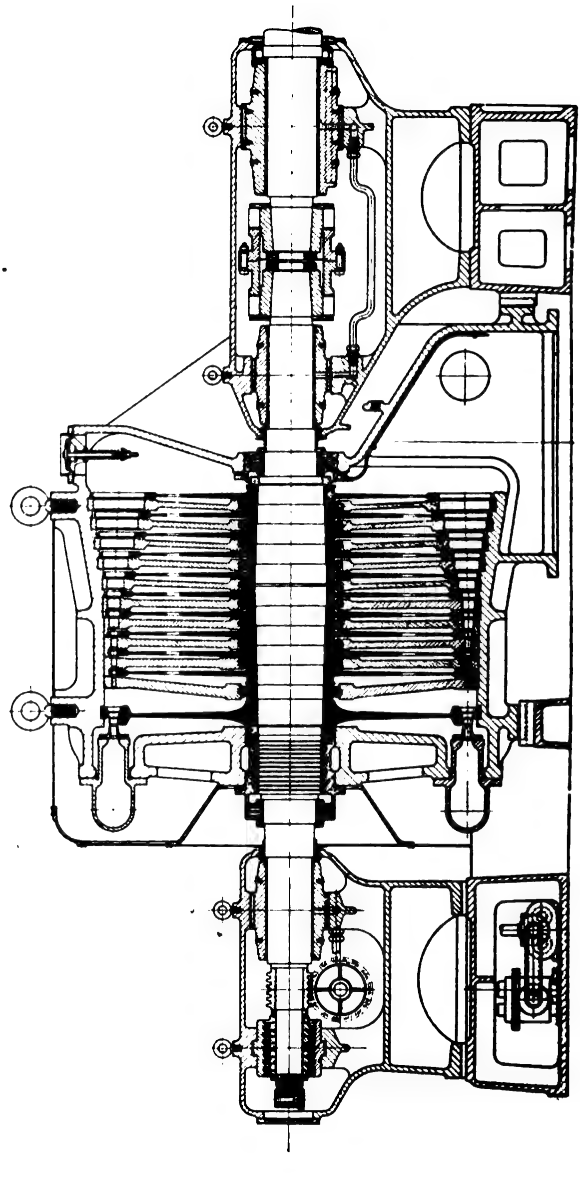


FIG. 19.—Modern Westinghouse Rateau Steam Turbine, 1910.

Dividing the turbines into three categories :—

1. Turbines with small outputs less than 750 k.w. at 3,000 revs. per minute, or less than 2,250 k.w. at 1,500 revs. per minute ;
2. Turbines with moderate outputs, 750–1,500 k.w. at 3,000 revs. per minute, or 2,250–4,500 k.w. at 1,500 revs. per minute ;
3. Turbines with large outputs, above 1,500 k.w. at 3,000 revs. per minute, or above 4,500 k.w. at 1,500 revs. per minute ;

we can state the relative position to be as follows :—

For turbines with small outputs the disc and drum type is certainly cheaper—*i.e.*, the disc and drum type can be made at a lower price for the same steam consumption, or allowing the same price for both types, the disc and drum turbine can be made with the better efficiency.

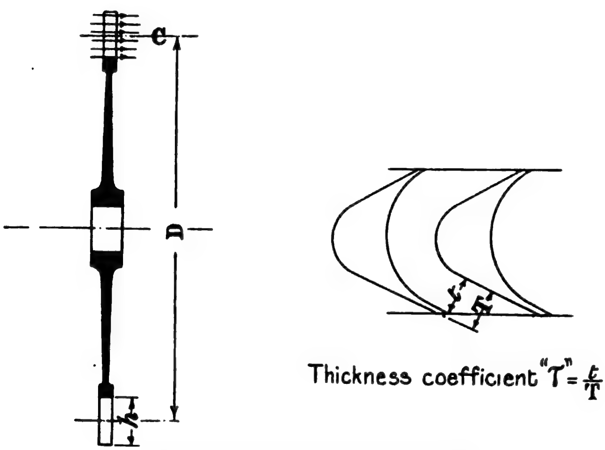


FIG. 20.—Last Wheel of Turbine.

For moderate outputs the two systems are about equal with regard to economy and first cost.

For large outputs, the Curtis-Rateau turbine is the better because the disc and drum type would have to be made as a double-flow turbine, in the low-pressure part, which would increase the cost of the turbine considerably without a corresponding increase in efficiency.

In short—

The drum turbine is the design for small outputs.
The disc turbine is the design for large outputs.

The following investigation proves that the maximum output which can be obtained with a disc turbine, under the same conditions with regard to working stresses, leaving losses and vacuum, is about twice as large as the maximum output which can be obtained with a drum turbine.

IV. Maximum Outputs of Turbines.

The maximum output for which steam turbines can be designed depends on the maximum weight of the steam which can be passed through the low-pressure part with reasonable efficiency. The greater the steam quantity the greater the output of the turbine.

The weight of steam is given by the following formula :—

$$G = \frac{V}{v} = \frac{\tau \pi D h c}{v} \quad \ldots\ldots\ldots\ldots \quad (1)$$

and the maximum output in kilowatts by—

$$N = \frac{\tau \pi D h c}{v S} \times 3{,}600 \quad \ldots\ldots\ldots \quad (2)$$

where—

G = weight of steam flowing through the turbine.
V = volume of steam flowing through the last blades.
v = specific volume of steam at exhaust.
D = mean diameter of last blades (see Fig. 20).
h = length of last blades.
c = axial steam velocity through last blades.
S = steam consumption per kilowatt-hour.
τ = thickness coefficient (0·90–0·95).

Hence the maximum output depends mainly upon :—

1. The specific volume v at the exhaust of the turbine which depends on the vacuum.
2. The outlet velocity c, which depends on the permissible leaving loss.
3. The mean diameter D, which depends upon the maximum permissible peripheral speed.
4. The maximum permissible blade height, which depends on the method of fixing the blade.

1. *Influence of Vacuum.*—The specific volume of the steam depends mainly on the vacuum, and its value for saturated steam from 27 in. up to 29 in. is given in the following table :—

Table I.

27 in.	27½ in.	28 in.	28½ in.	29 in.
231	274·5	338·6	440	654·5 cub. ft./lbs.
14·4	17·15	21·1	27·5	40·8 m.³/kg.

This table indicates that the maximum output which a turbine can be designed to give depends mainly on the vacuum, and is, other

conditions remaining the same, about 2·83 times larger at 27 in. than at 29 in. vacuum. In order, therefore, to compare the drum with the disc turbine, as regards maximum output, we must assume the same vacuum for both.

2. *Influence of Leaving Losses.*—In order to reduce the leaving loss to a minimum the blading should be so arranged that the absolute outlet velocity from the last wheel is in an axial direction.

If—

i_2 = total heat drop available.
c = the absolute outlet velocity from the last wheel.
J = mechanical equivalent of heat.
= 424 (metric units) or 778 (English units).

The leaving loss of the turbine is given by—

$$\left.\begin{aligned} l_0 &= \frac{c^2}{2\,g\,J\,i_2} \\ \text{In metric units—}\quad l_0 &= \frac{c^2}{91{\cdot}5^2\,i_2} \\ \text{In English units—}\quad l_0 &= \frac{c^2}{224^2\,i_2} \end{aligned}\right\} \quad \ldots \ldots \quad (3)$$

Allowing for the pressure drop through the governor valve, the total heat drop available with the standard high-pressure turbine conditions, mentioned on page 806, namely 180 lbs. per square inch gauge, 150° F. superheat, and 28 in. vacuum, is 200 calories or 360 B.Th.U.

Therefore—

$$\left.\begin{aligned} l_0 &= 0{\cdot}6\left(\frac{c}{100}\right)^2 \text{ per cent. for metric units} \\ l_0 &= 0{\cdot}0555\left(\frac{c}{100}\right)^2 \text{ per cent. for English units} \end{aligned}\right\} \quad \ldots \quad (3a)$$

Hence the maximum output is proportional to the square root of the leaving losses, and we get:—

Leaving loss, per cent....	1	2	3	4	5
Outlet velocity	129	182·5	223·5	258	289 m./sec.
Outlet velocity	424	598	733	846	948 ft./sec.

3. *Influence of Stresses in Drums and Discs.*—The maximum mean diameter D of a turbine depends on the peripheral velocity $u = \frac{\pi D n}{60}$, which itself is limited by the maximum stresses allowable. These are considered separately for drums and discs in the following investigation:—

(*a*) *Stresses in Drums.*—The stresses in rotating drums without

blades can be calculated very easily by the formula used for calculating stresses in rotating rings—

$$\sigma = \mu \, u_d^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

σ = tangential stress in drum.
μ = specific mass of material. (For steel 8×10^{-6} kg. cm.$^{-4}$ sec.^{2} or $7{\cdot}35 \times 10^{-4}$ lbs.-inch^{-4} sec.^{2}.)
u_d = mean peripheral speed of drum.

According to this formula, the following table has been calculated:—
In metric units—

u_d =	50	75	100	125	150 m./sec.
σ =	200	450	800	1,250	1,800 kg./cm.^{2}.

In lbs.-inch units—

u_d =	100	200	300	400	500 ft./sec.
σ =	1,060	4,230	9,530	16,930	26,460 lbs./square inch.

If the drum is loaded with blades we have to consider an additional stress which can be calculated from the expression:—

$$\sigma' = \sigma_0 \frac{r}{\delta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where—

σ' = additional stress in drum due to the centrifugal force of the blades.
σ_0 = load on drum due to the centrifugal force of the blades per unit surface (lbs./square inch or kg./cm.^{2}).
r = mean radius of drum.
δ = thickness of drum.

At the low-pressure end of the drum this additional stress is generally about 25 per cent. of the stress due to the centrifugal force of the drum itself, so that the total stress is approximately—

$$\sigma_{tot.} = 1{\cdot}25\,\sigma = 1{\cdot}25 \times \mu \times u_d^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The blade height of the last row is usually not more than one-fifth of the diameter so that—

$$\text{Mean } D = 1{\cdot}25\, D_d,$$

and—

$$\text{Mean } u = 1{\cdot}25\, u_d\,;$$

and therefore—

$$\sigma_{tot.} = 1{\cdot}25\, u_d^2 = \frac{1{\cdot}25\,\mu \,.\, u^2}{(1{\cdot}25)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

or—

$$\sigma_{tot.} = 0{\cdot}8\,\mu \,.\, u^2.$$

The maximum stress should not exceed—

One-third of the elastic limit, or about
One-fifth of the tensile strength of the material.

The physical properties of the steel available for commercial manufacture of drums and discs are given in the following table :—

TABLE II.

Material.	Breaking Strength.		Elastic Limit.		Elongation.	Maximum Stress.	
	Kg./cm.².	Lbs./sq. in.	Kg./cm.².	Lbs./sq. in.	Per Cent.	Kg./cm.².	Lbs./sq. in.
Forged steel ...	4,700	67,000	2,840	40,000	20	940	13,300
3 per cent. Ni-steel	6,300	90,000	—	—	18	1,250	17,800

According to these stresses the mean blade velocity should not exceed—

$u = 120$ m./sec. or 400 ft./sec. for forged steel drums.
$u = 140$ m./sec. or 465 ft./sec. for 3 per cent. Ni-steel drums.

(*b*) *Stresses in Discs.*—In a rotating disc there are two different kinds of stresses—

$\sigma_r =$ stress in radial direction.
$\sigma_t =$ stress in tangential direction.

For any point on a circle of radius r the stresses σ_r and σ_t remain constant, and for plain steel discs of uniform thickness are given by—

$$\left.\begin{aligned}\sigma_r &= \frac{3{\cdot}3\,u^2}{10^6}\left[1-\left(\frac{r}{r_2}\right)^2\right]\\ \sigma_t &= \frac{3{\cdot}3\,u^2}{10^6}\left[1-0{\cdot}575\left(\frac{r}{r_2}\right)^2\right]\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The stresses reach a maximum in the centre of the disc where—

$$\sigma_r = \sigma_t = \frac{3{\cdot}3}{10^6}u^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Thus the maximum stresses in the case of a plain rotating disc are only—

$$\frac{3{\cdot}3}{8} = 41{\cdot}25 \text{ per cent.}$$

of those of a drum rotating at the same peripheral speed; or, in other words, to obtain the same stresses a plain rotating disc must be run with a peripheral speed 55·5 per cent. higher than that of a rotating

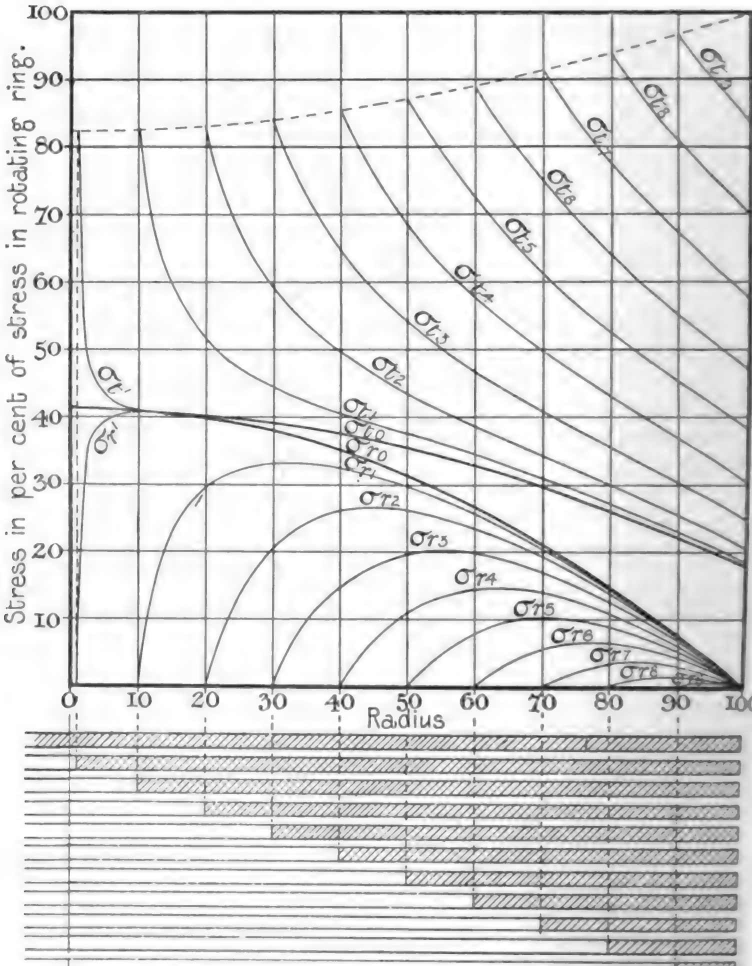


FIG. 21.—Distribution of Stresses in Uniform Disc with Hole.

ring or drum. The distribution of the radial and tangential stresses in the disc are shown in Fig. 21 by curves σ_{r_0} and σ_{t_0}.

Unfortunately discs used for steam turbines must be provided with

a hole at the centre for the purpose of fixing them on to the shaft. If the diameter of the hole be r_1 the stresses are given by—

$$\left.\begin{aligned} \sigma_r &= \frac{3{\cdot}3\, u^2}{10^6}\left[1 + \left(\frac{r_1}{r_2}\right)^2 - \left(\frac{r}{r_2}\right)^2 - \left(\frac{r_1}{r}\right)^2\right] \\ \sigma_t &= \frac{3{\cdot}3\, u^2}{10^6}\left[1 + \left(\frac{r_1}{r^2}\right)^2 - 0{\cdot}575\left(\frac{r}{r_2}\right) + \left(\frac{r_1}{r}\right)^2\right] \end{aligned}\right\} \quad . \quad . \quad (10)$$

The distribution of stresses in discs with holes of various diameters is plotted in Fig. 21. If the hole is very small the stress σ_r on its periphery will become zero, the stress falling according to the curve $\sigma_{r'}$.

On the other hand, the reduced stress $\sigma_{r'}$ must obviously be balanced by an increased stress $\sigma_{t'}$, and from the formula given above calculation shows that the tangential stress near the periphery of the hole is increased to double the stress in a solid disc without a hole.

This means that a disc with a very small hole is only very little stronger than a ring rotating with the same peripheral velocity. For larger holes the tangential stresses increase still more (see Fig. 21), the radial stresses decreasing at the same time, and for a very large hole the disc finally takes the form of a ring, σ_r becoming very small and σ_t equal to the stress for a ring.

A plain disc with a hole in the centre is not, however, strong enough for turbine work, and it is therefore necessary to increase its strength. This may be done in the following manner :—

1. Strengthening the disc near the periphery of the hole by a boss.
2. Increasing the thickness of the disc towards the centre in order to obtain as nearly as possible a disc of uniform strength.

The different kind of disc shapes at present used in turbine practice are shown in Fig. 22.

Fig. A shows a plain tapered disc with cylindrical boss in which $\frac{y_1}{y_2} = 1{\cdot}77$.

Figs. B and C show a tapered disc with a hyperbolic profile, increasing the thickness towards the boss.

$$\text{For wheel B } \frac{y_1}{y_2} = 2{\cdot}35,$$

$$\text{For wheel C } \frac{y_1}{y_2} = 4{\cdot}17.$$

The values of the stresses in these cases are shown by the curves σ_r and σ_t. It has been found that the maximum stress is always a tangential stress and (for disc A) is given by the formula—

$$\text{Maximum } \sigma_t = 4{\cdot}4 \times 10^{-6}\, u^2.$$

For disc B—

$$\text{Maximum } \sigma_t = 3{\cdot}3 \times 10^{-6}\, u^2.$$

For disc C—

$$\text{Maximum } \sigma_t = 2{\cdot}7 \times 10^{-6}\, u^2.$$

This means that, compared with a plain disc of uniform thickness, disc B is of equal strength, disc A is 33 per cent. weaker, and disc C is 18 per cent. stronger.

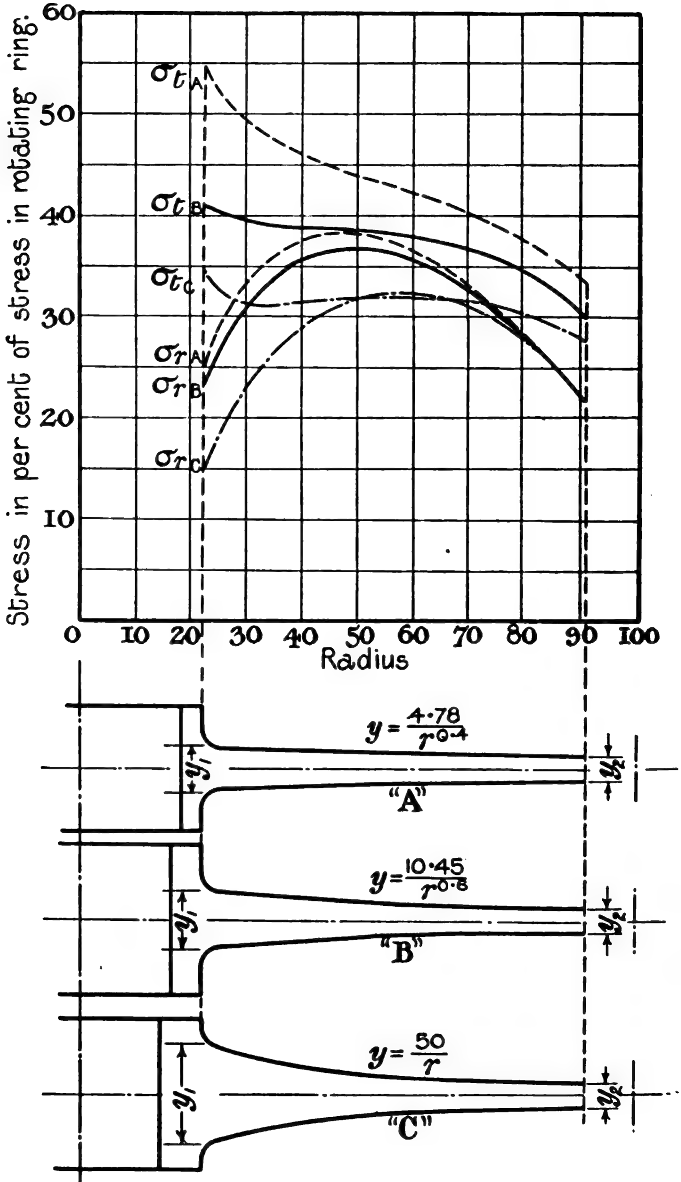


FIG. 22.—Distribution of Stresses in Turbine Discs.

Allowing maximum permissible stresses according to Table II., these discs can be run up to the peripheral speeds shown on page 799.

Thus in the case of disc A the peripheral velocity can be 1·35 times, disc B 1·55 times, and disc C 1·72 times the maximum velocities for drums. Mild steel discs of shape B which represent usual practice can be run at a peripheral velocity of 168 m./sec., so that for—

$n = 3{,}000$ revs. per minute the mean diameter would be $= 42$ in.,

or—

$n = 1{,}500$ revs. per minute the mean diameter would be $= 84$ in.

4. *Influence of Stresses in Blading.*—It will be seen from the formulæ which we are discussing that the maximum steam quantity is proportional to the blade height. The larger the blade height the larger the

Peripheral Velocity of Discs.

	Forged Steel.		3 per Cent. Ni-steel.	
	M./sec.	Ft./sec.	M./sec.	Ft./sec.
Disc shape A ...	146	478	168	552
Disc shape B ...	168	555	194	636
Disc shape C ...	186	610	215	705

steam quantity and also the output. The stress at the blade root is given by—

$$\sigma_b = 2\,\mu\,u^2\left(\frac{h}{D}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where—

$\sigma_b =$ stress in the blade root.
$\mu =$ the specific mass of material.
$u =$ peripheral velocity.
$h =$ blade height.
$D =$ mean diameter of disc.

(*a*) *Drum Turbines.*—As the ratio $\frac{h}{D}$ is generally less than $\frac{1}{5}$, the stress at the root of the blades (for drum turbines) is $\sigma_b = \frac{2}{5}\,\mu\,u^2$, *i.e.*, only half of the stress of the drum which has been shown to be $\sigma = 0{\cdot}8\,\mu\,u^2$. In drum turbines, therefore, the blade height is only dependent upon the reliability of the method employed for fixing the blades to the drum. If the turbine is to realise its maximum permissible output, blades of considerable length are required, and these cannot be held rigidly enough if the usual methods of caulking the distance-pieces are used ;

consequently methods similar to those at present applied to impulse turbines must be adopted.

It can be shown that there are available methods of fixing the blading with which no stress in any part is produced larger than that at the root, and since, as shown by the above formulæ, this stress is of no importance, the maximum height of the blades in drum turbines is limited by other considerations; in order to keep the difference of the peripheral speeds at the root and at the top of the blades within practical limits it is not advisable to increase the blade height above one-fifth of the mean diameter D, as already pointed out.

(*b*) *Disc Turbines.*—The blade height which can be used in disc turbines is dependent upon the stress at the root of the blade.

Taking the maximum blade height of Rateau turbines to be one-fifth of the mean diameter, the stress at the root of the blade is—

$$\left.\begin{aligned}\sigma_b &= \tfrac{2}{5}\,\mu\,u^2 \quad . \quad . \quad . \\ &= 3{\cdot}2\,u^2 \times 10^{-6}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

i.e., about the same as the stresses in a disc of shape B, Fig. 22.

The following table gives the values of this stress for different peripheral speeds:—

For $u = 100$	125	150	175	200	m./sec.		
$= 320$	500	720	980	1,280	kg./cm.².		
For $u = 100$	200	300	400	500	600	700 ft./sec.	
$= 423$	1,693	3,810	6,773	10,584	15,240	20,740 lbs./sq. in.	

Assuming for disc turbines that $h = \frac{D}{5}$, formula (2) becomes—

$$\text{Maximum output in KW} = \frac{\tau\,\pi}{5}\,\frac{D^2 c}{v\,S} \times 3{,}600 \quad . \quad . \quad . \quad (12a)$$

Hence the maximum output is proportional to the square of the diameter.

5.—*Maximum Outputs of Disc as Compared with Drum Turbines.*—In order to compare the two different types of turbines, it is, of course, necessary to assume the same outlet losses.

From formula (2) it follows that—

$$K\,W_{drum} = \frac{\tau\,\pi\,D_{drum}\,h_{drum}}{v\,S}\,c \times 3{,}600.$$

$$K\,W_{disc} = \frac{\pi\,\tau\,D_{disc}\,h_{disc}\,c}{v\,S} \times 3{,}600$$

c, v, and S being the same in both cases.

$$\frac{K\,W_{drum}}{K\,W_{disc}} = \frac{D_{drum}\,h_{drum}}{D_{disc}\,h_{disc}} = \left(\frac{D_{drum}}{D_{disc}}\right)^2 \quad . \quad . \quad . \quad . \quad (13)$$

$$\text{as } h = \frac{D}{5} \text{ in both cases.}$$

For a given number of revolutions of the turbine, the diameter is proportional to the peripheral speed and the output, and for the same stress in discs and drums—

$$\frac{KW_{\text{drum}}}{KW_{\text{disc}}} = \left(\frac{u_{\text{drum}}}{u_{\text{disc}}}\right)^2 = \frac{3{\cdot}3}{6{\cdot}4} = \frac{1}{2} \text{ approximately} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

which means that, other conditions remaining the same, a disc turbine can be built having twice the maximum output of a drum turbine.

The fact that some makers have recently begun to use solid drums, which, according to our investigation, would theoretically be stressed only to the same figure as disc turbines, does not alter the above statement with regard to relative capacity, because it is unsafe to run solid drums at a higher peripheral speed than ordinary drums. This is due to small faults in their interior which it is quite impossible to detect, and which have been shown to increase the calculated stresses to more than double. Both the disc and the ordinary drum construction have the advantage of allowing inspection to be made of each part, thus ensuring that the material is homogeneous throughout.

6. *Maximum Outputs obtainable from Disc Turbines.*—The maximum output of a disc turbine, being proportional to the square of the diameter is—for a given permissible stress—inversely proportional to the square of the revolutions per minute.

Consequently the output of a turbine is—

4	times larger at	1,500	revs. per minute	than at	3,000	revs. per minute.
9	,, ,,	1,000	,,	,,	3,000	,,
16	,, ,,	750	,,	,,	3,000	,,

In practice, however, it is not advisable or necessary to stress the material in large turbines to the same extent as in small turbines, so that the relation between speed and output may be taken as follows:—

Maximum output for 1,500 revs. per minute, 3 times larger than for 3,000 revs. per minute.
Maximum output for 1,000 revs. per minute, 5 times larger than for 3,000 revs. per minute.
Maximum output for 750 revs. per minute, 8 times larger than for 3,000 revs. per minute.

These figures can be approximately obtained from the formula—

$$\text{Maximum output} = \frac{\text{Constant}}{n^{3/2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

from which the maximum output for any speed can be obtained, other conditions remaining the same if the maximum output for any one speed is known.

As the stresses are proportional to the square of the diameter for a given speed, it follows that, other conditions remaining the same, the maximum output is proportional to the tensile strength of the material.

The maximum output is effected in the same way by the decrease of stress obtained by improving the disc and blade shape.

For a given turbine of, say, 42 in. mean diameter, running at 3,000 revs. per minute, the maximum output depends only on the vacuum and

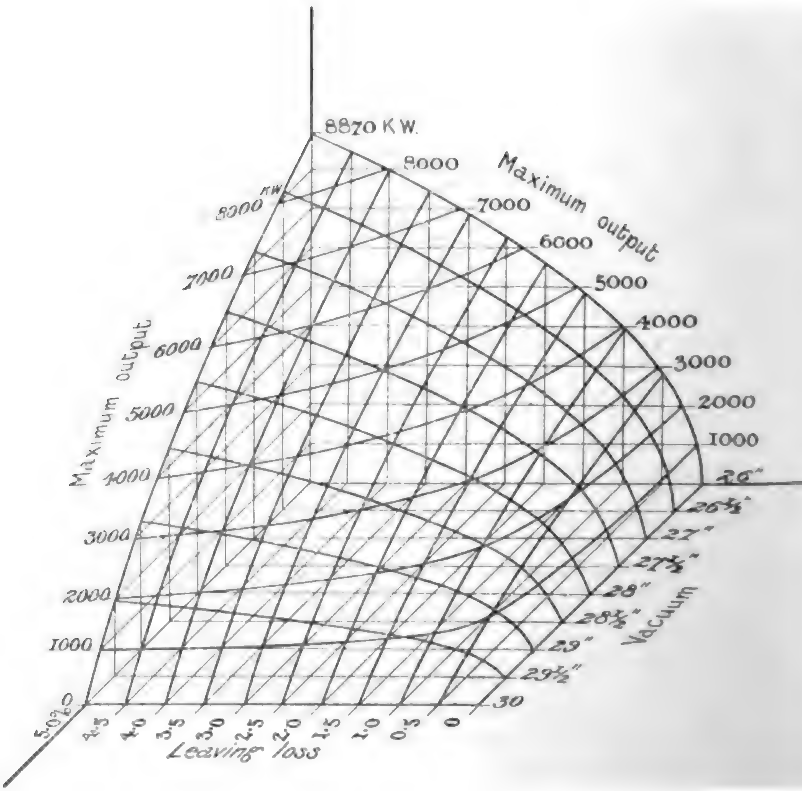


FIG. 23.—Maximum Output obtainable from Disc Turbines.

the leaving losses. The relations between these quantities have been plotted in Fig. 23 in the calculation of which the following figures were assumed :—

Initial pressure ... ... = 180 lbs./sq. in. gauge.
Superheat ... ... = 150° F.
Turbine efficiency ... ... = 70 per cent.
Generator efficiency ... ... = 94 per cent.
Specific volume as in Table I., allowing for 6 to 8 per cent. moisture.
Thickness coefficient for last wheel = 0·92 to 0·94 per cent.

7. *Recent Development of Outputs of Turbo-generators.*—The question of the maximum outputs, which can be obtained with the different types of turbines, becomes very important in view of the great increase in the maximum capacities of turbo-alternators during the last three years. This is mainly due to the rapid development of the impulse turbine, the high costs of which for small outputs and great economy for large outputs have caused the manufacturers of these turbines to introduce designs of turbo-generators suitable of giving very large outputs at relatively high speeds. Whereas four years ago 1,000 k.w. was considered a very large output for 3,000 revs. per minute, manufacturers are at present prepared to go up to 3,000 k.w., and even higher for this speed. The increase of the output of turbo-alternators has been more rapid in the United States and on the Continent than in this country. For example: The American Westinghouse Company recently built 5,000 k.v.a. running at 3,600 revs. per minute, and 15,000 k.w. maximum rating at 1,800 revs. per minute. The A.E.G. Company is reported to have in work 21,500 k.v.a. at 1,000 revs. per minute,* and Siemens-Schuckert Works 4,000 k.v.a. at 3,000 revs. per minute.

V. The Critical Speed of Turbine Rotors.

In the design of steam turbines a most important factor is the critical speed of the rotor. In this matter the disc type of turbine has a very considerable advantage over the drum, in that its critical speed can be calculated with ease and certainty, and that it can be satisfactorily balanced by statical methods.

The first turbines of the Rateau and Zoelly type were made with a flexible shaft, *i.e.*, the normal speed was above the first critical speed. At one time there was even a tendency to neglect the critical speed altogether, in spite of the investigations made by Professor Stodola, as it was found that turbines, if properly balanced, could, under normal condition, be run very satisfactorily even at the critical speed. Unfortunately it was soon found in commercial running, when abnormal conditions are bound occasionally to occur, that if the shaft were deflected—as, for instance, when water is carried over with the steam—it remained deflected because it was running at the critical speed.

The question of the critical speed is of the first importance when using the three-bearing design, which is becoming more generally adopted for small turbines. It will therefore be of some interest to recall the main facts relating to critical speeds of rotors, as used for turbines, generators, blowers, compressors, and pumps.

The critical speed of a shaft is usually defined as that speed at which a very small eccentric mass will cause the shaft to deflect to a very great extent. It can be demonstrated that this speed coincides with the natural frequency of vibration of the shaft, and also that it is that speed at which any accidental deflection of the shaft results in a

* See A.E.G., Zeitung, 1911–12.

centrifugal force due to its rotation about its position of rest, sufficiently large to maintain this deflection.*

In the following investigation a shaft will be referred to as rigid if its critical speed is above the normal running speed, and as a flexible shaft if its critical speed is below the normal running speed.

1. *Critical Speed of a Weightless Shaft with One Wheel.*—When a vertical shaft loaded with one wheel of mass M is run much below the critical speed it retains its straight position (Fig. 24). On the other hand, a horizontal shaft has an initial deflection, due to the weight of mass M (Fig. 25), and if caused to rotate will still keep this configuration—*i.e.*, the deflection of the shaft, due to the weight, will remain the same, and the shaft will not straighten itself, as might be expected at first sight.

In either case if the shaft is run much below the critical speed, and is for any reason deflected from its position of rest, the elastic forces of

FIG. 24.

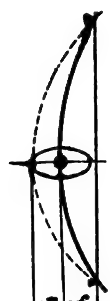


FIG. 25.

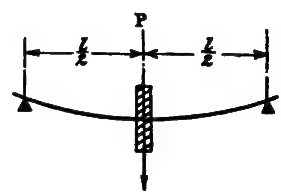


FIG. 26.

the shaft will restore it to its original position. The critical speed is reached when the deflection of the mass M, owing to its rotation about its position of rest, produces a centrifugal force sufficiently large to maintain this deflection.

It is evident, therefore, that the critical speed of a shaft is the same whether in a vertical or a horizontal position, as the additional deflection due to centrifugal force is identical in either case. In general terms this means that the position of the shaft does not influence its critical speed.

It is clear from the above that the governing condition of the critical speed is that the centrifugal force P, which is equal to $M y \omega^2$, must be large enough to keep the shaft in the deflected position, *e.g.*, in the case of the shaft shown in Fig. 26—

$$P = y \frac{48 \, E \, I}{l^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

* For a more complete investigation of the phenomena of critical speed see Professor Stodola's "Dampfturbine," 4th ed., upon which these remarks have been based.

where—

$E =$ modulus of elasticity.
$I =$ transverse moment of inertia.
$l =$ length of shaft.
$y =$ maximum of deflection.

More generally $P = a\,y$, where—

$a =$ constant for given shaft, position of weight, and method of support.
$y =$ deflection of the shaft measured at the point where the weight is carried.

This formula, combined with $P = M\,y\,\omega^2$, will give—

$$M\,y\,\omega^2 = a\,y,$$

or—

$$M\,\omega^2 = a \qquad (17)$$

Thus the critical speed is independent of the deflection imparted to the shaft, or, in other words, a shaft running at the critical speed is in neutral equilibrium.

Although the critical speed *has really nothing whatever to do with the deflection due to gravity*, there is a very simple relation between the critical speed and the deflection f of the shaft, due to the weight of mass M when supported horizontally.

The relation is given by—

$$G = M\,g = a\,f \qquad (18)$$

Combining (17) and (18) we get—

$$f\,\omega^2 = g \qquad (19)$$

where—

$f =$ the deflection of the shaft due to the weight, and is measured at the point where the weight is carried.
$\omega =$ critical angular velocity in radians/seconds.
$g =$ constant of gravitation.

This formula applies to any weightless shaft loaded with one concentrated mass in any position and for any method of support. A few of the most important cases are illustrated in Fig. 27.

It will subsequently be proved that by a very slight modification of the constant this formula can be used equally well for shafts with any distribution of load which may occur in practice.

2. *Critical Speed of Shafts with Uniformly Distributed Loads.*—For a uniform shaft with a uniformly distributed load it can again be demonstrated that the critical speed corresponds to the natural frequency of vibration. The critical speed is given by the following

formula for all the five different methods of support illustrated in Fig. 28:—

$$\omega = k^2 \frac{\pi^2}{l^2} \sqrt{\frac{\mathrm{I\,E}}{m}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

where—

l = length of shaft, as shown in Fig. 28.
I = transverse moment inertia of shaft.
E = modulus of elasticity.
$m = \frac{w}{g}$ mass per unit length.
w = weight, load per unit length.

If only one weight be used there is but one critical speed, and as the speed is raised above this the running becomes steadier. Extensive use of this fact has been made by de Laval in his single-wheel

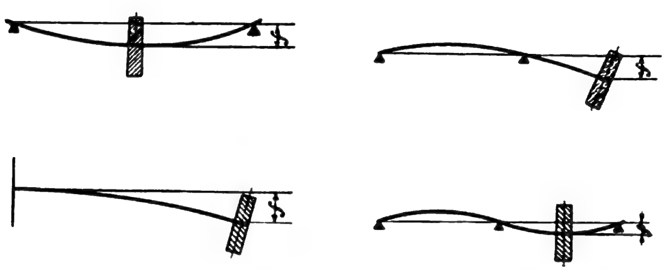


FIG. 27.—Different Cases of Concentrated Loading.

turbine, in which, in order to reduce vibration, the running speed is seven times greater than the critical speed.

If more than one weight be used the shaft will have critical speeds of higher frequency, and in the case of shafts with uniformly distributed loads there are theoretically an infinite number of critical speeds, of which, however, only the first, second, and in exceptional cases the third and fourth, are of practical importance.

The constants k and k^2 for these different critical speeds are given in Fig. 28 together with the corresponding elastic curves, which are characteristic of them. With the help of this table, all important critical speeds, or natural frequencies of vibration, can be calculated for any of the conditions given.

The first, or fundamental critical speeds are, of course, of the greatest importance, and for the different cases their relative values are given by the constant k^2.

Case	1	2	3	4	5
$k^2 =$	0·356	1·0	1·56	2·25	1

This shows, for instance, that the critical speed of the overhung shaft is about one-third of that of a shaft supported in two bearings.

It is very important to know the second critical speed of shafts

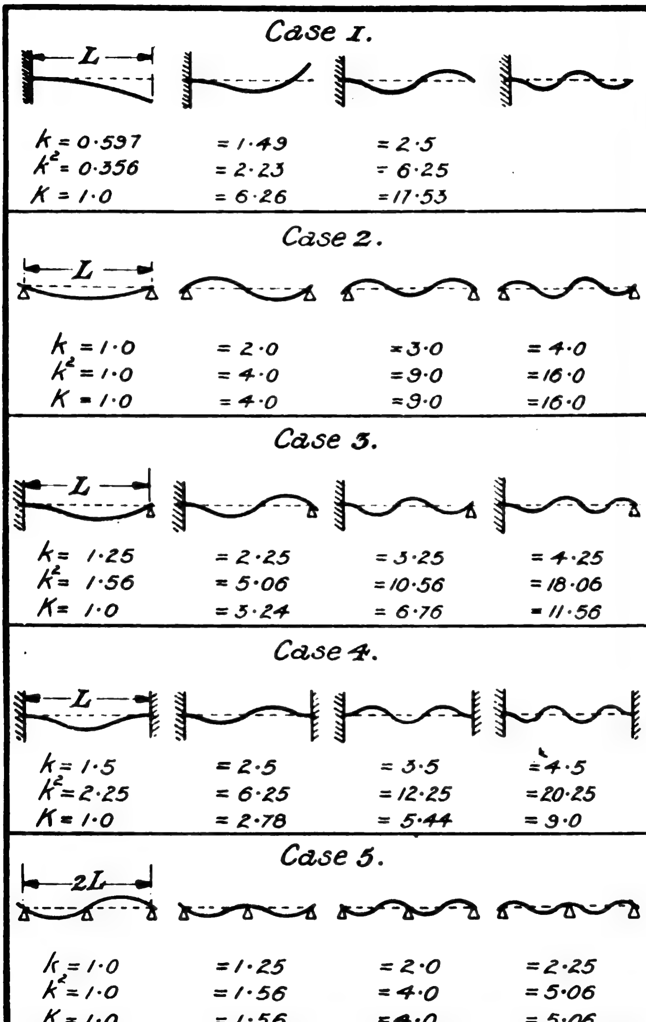


FIG. 28.—Critical Speeds of Shafts with Uniformly Distributed Loads.

running above the first, because it is essential that the running speed be sufficiently removed from both the first and the second in order to reduce the vibration to a small amount. Also, it is very often impossible

to calculate the critical speed with absolute accuracy, and, consequently, it should be made a standard practice to have the running speed at least 30 per cent. above or below any critical speed.

The ratios of the higher critical speeds to the fundamental are given by the value of K in Fig. 28.

For case 1 the second critical speed is 6·26 times higher than the first; for case 2, 4 times; case 3, 3·24 times; case 4, 2·78 times; and for case 5, only 1·56 times higher. In the last case, which often occurs in practice, and is known as the three-bearing design, this figure may be further reduced by the use of smaller shaft diameters in the centre bearing, from which the practical difficulties of a three-bearing machine, running between the first and second critical speed, are apparent. This statement is only correct when the critical speeds of both the spans are about equal.

When one span is a rigid and the other a flexible shaft, the combined effect raises the first critical speed of the flexible shaft to a maximum determined by the ratio of the first critical speed of case 2 to that of case 3, and the second critical speed may be sufficiently far from the first to render a three-bearing machine, running above the first critical speed, quite practicable. It will, however, always be necessary for the designer to satisfy himself as to the approximate position of the different critical speeds. For this purpose Fig. 28 will be of considerable help.

We will now proceed to find a relation between deflection due to gravity and the first critical speed. In all five cases the maximum deflection due to a uniformly distributed load is given by the following formula:—

$$f = c \frac{m}{\mathrm{I\,E}} l^4 g \qquad (21)$$

The values of the constant c are—

For case	1	2	3	4	5
$c=$	1/8	5/384	1/185	1/384	5/384

Combining formula (20) with (21) we get—

$$f \omega^2 = c\, k^4 \pi^4 g \qquad (22)$$

writing—

$$\gamma = c\, k^4 \pi^4$$

we get—

$$f \omega^2 = \gamma g \qquad (23)$$

The value of γ for the different cases being:—

Case	1	2	3	4	5
	1·55	1·27	1·35	1·29	1·27

(23) is of similar form to the formula found for the critical speed of a

weightless shaft with one wheel. The additional factor γ shows that the critical speed given by—

$$f\omega^2 = g$$

is to be multiplied by the coefficient $\sqrt{\gamma}$ in order to obtain the exact critical speed for the different cases, *i.e.*—

Case ...	1	2	3	4
By $\sqrt{\gamma} =$	1·25	1·13	1·16	1·13

In all five cases the difference in the value of the coefficient is remarkably small, and they cover nearly all possible arrangements of shafts.*

Considering the actual distributions of loading are combinations of concentrated and uniformly distributed loads, it will be an easy matter, by the aid of Fig. 28, to estimate to a very fine degree the limits of the factor $\sqrt{\gamma}$.

3. *Critical Speed and Deflections of Turbine Rotors.*—The author has had an opportunity of verifying the relation existing between the critical speeds and deflections for shafts as used in impulse turbines, blowers, and compressors.

By well-known methods the critical speed and deflection due to gravity were calculated (as accurately as possible by different engineers) with the invariable result that—

$$f\omega^2 = (1{\cdot}07 \text{ to } 1{\cdot}08)\,g\,;$$

or in cm. sec. units with $g = 981$ cm./sec.^{2}

$$f\omega^2 = 1{,}050 \text{ to } 1{,}060.$$

With this formula it is possible to answer at once the question, What is the maximum deflection of a turbine shaft running at 3,000 revs. per minute if the critical speed is 30 per cent. above the running speed?

$n = 3{,}900$ revs. per minute.

$\omega = 410$ sec^{-1}.

$$f = \frac{1060}{410^2} = 0{\cdot}0063 \text{ cm.} = 0{\cdot}063 \text{ mm.} = 2{\cdot}5 \text{ mils.}$$

For a turbine running at—

1,500 revs. per minute f would be 0·010 in.
1,000 „ f „ 0·022 „
750 „ f „ 0·040 „

VI. Governing of Steam Turbines.

Steam turbines are generally governed by a throttle valve, which is connected to a mechanical governor either directly or indirectly by means of steam or oil relay.

* This result is quite consistent with Dunkerley's Law. *Philos. Transactions of the Royal Society*, London, vol 185, p. 270, 1895.

Direct governing, which has been adopted from steam-engine practice, is very satisfactory for small turbines, provided the throttle valves are absolutely balanced; for larger turbines, steam relays with pulsating motion have been used, but now nearly all manufacturers of steam turbines use oil relays, and this is undoubtedly the most satisfactory arrangement.

In the case of combined turbines, governing by cutting-out nozzles improves the economy at partial loads. Special nozzles which were cut out by hand were first used by de Laval and later by the General Electric Company; the latter also introduced automatic nozzle cut-out governing, *i.e.*, an arrangement by which nozzle control valves, under the control of the speed governor, are opened in succession according to the load. Similar arrangements have been adopted by the A.E.G. in connection with their Curtis-Rateau turbines.

It has been stated that a disadvantage of the combined turbine is that it must be provided with nozzle cut-out governing at partial loads, in order to obtain satisfactory consumption at these loads. This, however, is not so, as there is, of course, no reason why ordinary throttle governing should give less satisfactory results at partial loads with combined turbines than with "pure" types of turbines. It is a fact that automatic nozzle control complicates the governing mechanism to such an extent that it should only be adopted in exceptional cases, where turbines are run for a considerable length of time at low loads and where the loads may change rapidly. In most cases ordinary throttle governing is preferable, as the small improvements obtainable with nozzle cut-out governing (2 per cent. at ¾ load, 4–5 per cent. at ¼ load) do not justify the additional complication in the governing apparatus. The practical difficulties of automatic nozzle control are due not to the necessity of arranging valves in front of the nozzles, but to the complicated gear required to operate the valves, which latter must be reasonably tight when closed. These difficulties, therefore, do not exist when hand-operated valves are used, and in most cases these meet the requirements. The problem of cut-off governing, which has been successfully solved for steam engines, is more difficult in the case of steam turbines, but it is also of less importance.

VII. Increase of the Field of Appication of Turbines.

1. *High-pressure Turbines.*—The steam turbine is the machine for large outputs, and it has during the first half of the last decade superseded the steam engines for outputs above 1,000 k.w. The recent improvements in steam turbines, which resulted from the adoption of the combined types, has still further reduced the minimum output at which a steam engine is more advantageous than a steam turbine. Units of 500-k.w. capacity are now usually ordered as turbines, and even 250-k.w. turbines are able to compete successfully with the best modern steam engines. In countries, as for instance the United States, where the cost of coal is of secondary importance, there is a tendency to adopt

turbines for even the smallest outputs. For small units generally the pure Curtis types with only a single wheel are used. These are also applied very successfully for special purposes, as, for instance, the driving of condenser and high-lift pumps, which are discussed more fully in the final paragraph.

The developments which have taken place during the last five years show an improvement not only in high-pressure condensing turbines as used for power stations, but also a tremendous increase in the application of turbines to all possible industrial purposes. This has involved the manufacture of new kinds of machines known at present as :—

Low-pressure or L.P. turbines.
Mixed-pressure or M.P. turbines.
Back-pressure or B.P. turbines.
Reducing or R. turbines.

2. *Low-pressure turbines.*—The great possibilities of low-pressure turbines was first pointed out by Professor Rateau, who invented the Rateau steam accumulator, which is really a necessary accessory for low-pressure installations. The first plant including low-pressure turbines and steam accumulator in conjunction with winding engines was installed by Professor Rateau in 1903 for the Mines de Bruay.

The Rateau accumulator allows low-pressure steam at a constant or approximately constant rate to be taken from a machine which is working intermittently. If the available low-pressure steam quantity is always sufficient for the output required, the installation of a low-pressure turbine is quite satisfactory, and if for short periods no low-pressure steam is available, high-pressure steam must be reduced into the low-pressure steam main. If, however, this occurs for long periods, or if the low-pressure steam quantity is not sufficient to produce the power required from the turbine, the losses due to throttling high-pressure steam to below atmospheric pressure are too large. In such cases, which represent the normal condition, the installation of a mixed-pressure turbine is necessary.

The main application of low-pressure turbines is at present in connection with steam engines without accumulators in existing power stations. Engines previously run condensing are changed to run non-condensing and allowed to exhaust into a low-pressure turbine, the alternator of which is coupled electrically to that on the steam engine, so that engine and turbine form one set.

This arrangement is very economical, providing the normal output of the combined set is increased at least 50 per cent. above that of the engine alone. Usually the combined set is arranged so that the normal full load of the engine alone when exhausting against a back pressure of about 16 lbs. per square inch absolute is kept the same as before, the low-pressure turbine utilising the exhaust steam coming from the engine. It is advisable to pass the exhaust steam from the engine through an oil separator which acts also as a water separator. The additional output which can be obtained from the low-pressure turbine

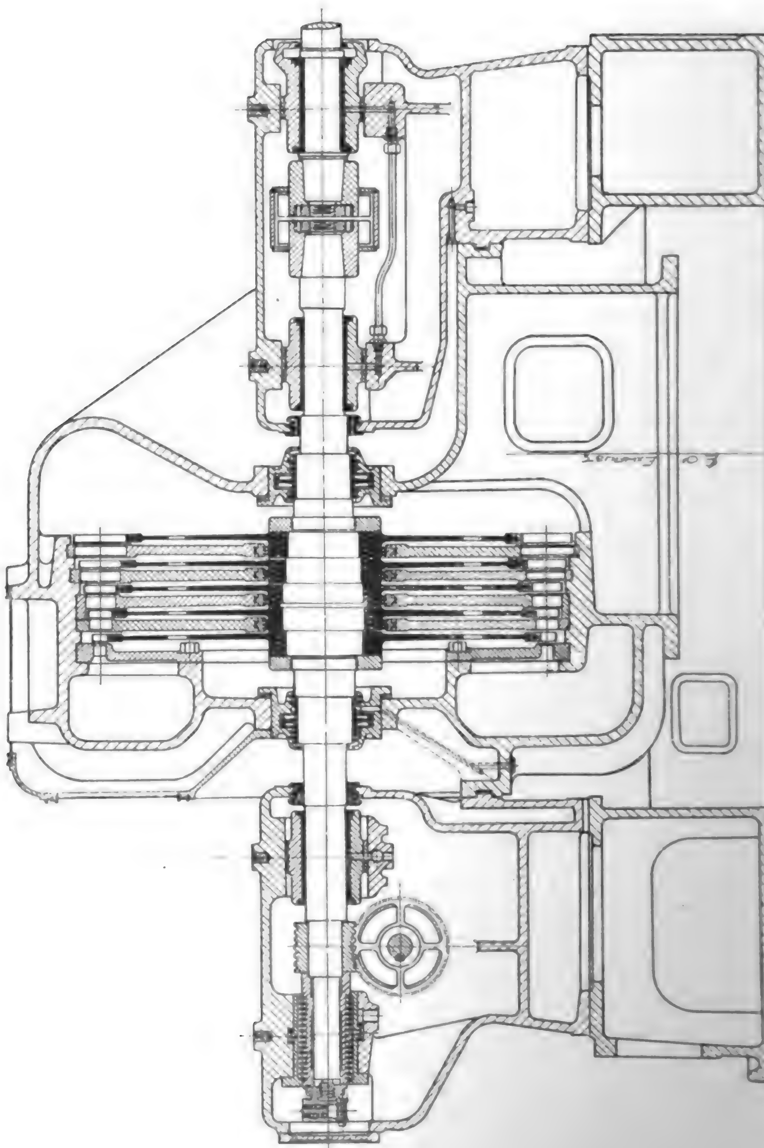


FIG. 29.—Low-pressure Turbine. The British Westinghouse Company, 1910.

depends mainly on the vacuum. The improvement in economy is much larger in cases where river or sea water is available for cooling water than in cases where cooling towers are necessary. At partial loads the back pressure on the steam engine drops below atmospheric pressure; it is therefore essential to steam-seal the glands on the low-pressure cylinders of the steam engine in order to reduce air leakage to an absolute minimum and to secure the highest possible vacuum.

The following figures are based on the average conditions which usually occur in these combined plants in the case of compound engines.

The steam consumption of the engine running non-condensing will be about 35 per cent. (30 per cent. to 40 per cent.) greater than when running condensing. The exhaust steam from the engines will give an additional output in a low-pressure turbine of :—

61 per cent. of the output of the engine at 27 in. vacuum,
70 " " " " 28 " "
81 " " " " 29 " "

and the steam or coal consumption would be :—

For 27 in. vacuum : $\frac{1{\cdot}35}{1{\cdot}61} = \Big\{$ 84 per cent. of the original steam consumption

" 28 " " $\frac{1{\cdot}35}{1{\cdot}70} = 80$ " " " "

" 29 " " $\frac{1{\cdot}35}{1{\cdot}81} = 75$ " " " "

As the turbine is electrically coupled to the engine, no special governing of the turbine is required. For starting and paralleling generally, high-pressure steam is required, which is either regulated by hand or by a mechanical governor. It is not necessary to provide a reducing valve, as the steam pressure in the low-pressure turbine will anyhow not be higher than atmospheric pressure, due to the very large areas through the blading of the turbine.

A section of a low-pressure turbine is illustrated in Fig. 29, from which it will be seen that it is simply a high-pressure turbine with the first wheels taken off. The section of this turbine shows five wheels with full admission, and the capacity is 1,000 k.w. at 2,700 revs. per minute.

3. *Mixed-pressure Turbines.*—Mixed-pressure turbines are high-pressure turbines with an additional inlet for low-pressure steam, or low-pressure turbines with additional high-pressure stages to utilise high-pressure steam in case the available low-pressure steam quantity is not sufficient for the load required. They are generally used in collieries, rolling mills, utilising low-pressure steam coming from different kinds of engines, which are exhausting against a back pressure of about 16 lbs. per square inch absolute into steam accumulators.

A section through a mixed-pressure turbine consisting of one velocity wheel and one Rateau wheel in the high-pressure part and five Rateau wheels in the low-pressure part is shown in Fig. 30.

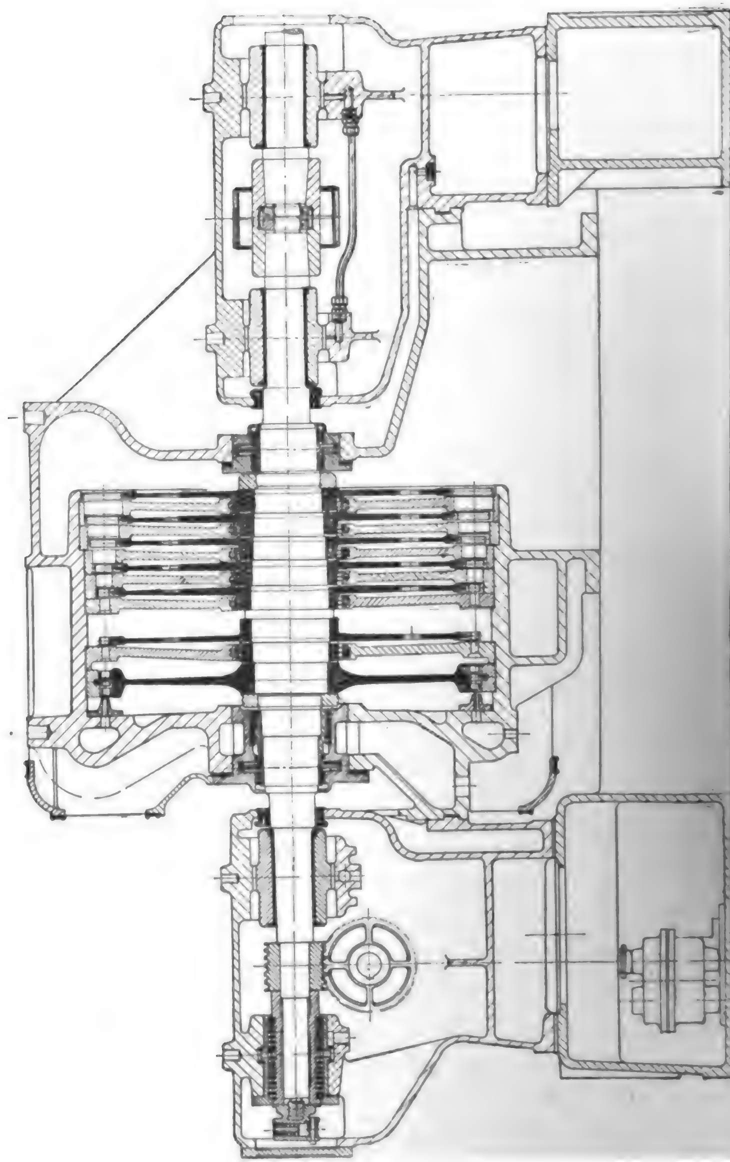


FIG. 30.—Mixed-pressure Turbine. The British Westinghouse Company, 1910.

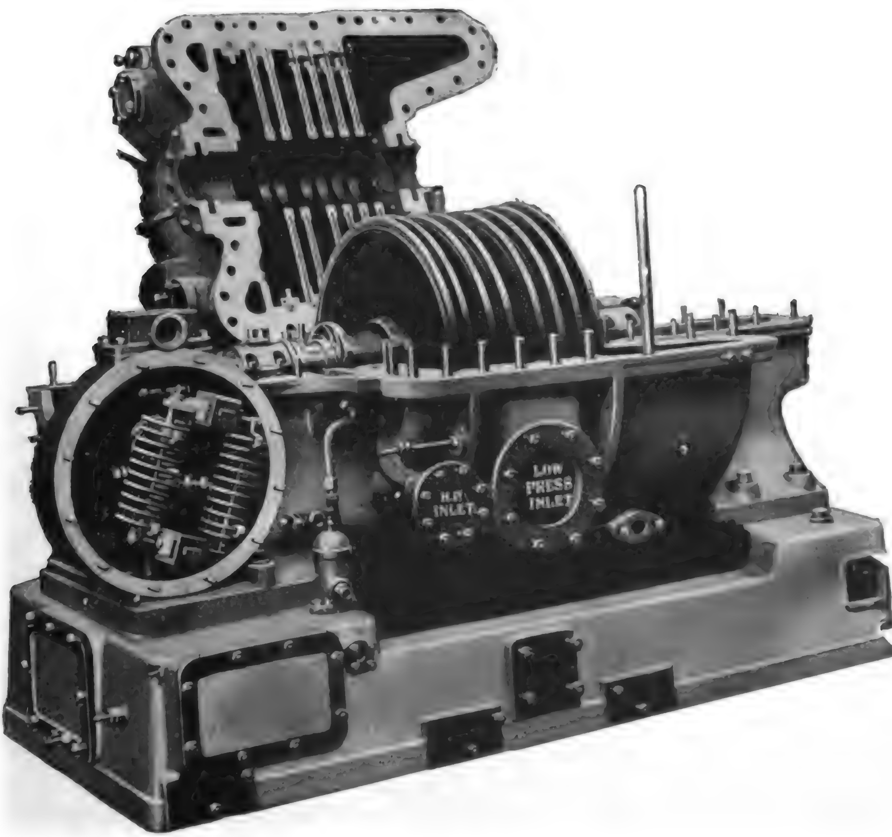


FIG. 31.—Mixed-pressure Turbine.

Fig. 31 shows a view of a mixed-pressure turbine consisting of one velocity wheel and two Rateau wheels in the high-pressure part, and four Rateau wheels in the low-pressure part.

Mixed-pressure turbines are not generally connected electrically with the steam engines from which the supply of low-pressure steam is obtained, and must therefore be separately governed by a speed governor. In order to obtain satisfactory running in parallel with other engines, it is essential that the load of the turbo-set be independent of the steam conditions, which means that the speed of the turbine must be only dependent upon the load of the alternator, and independent of the low-pressure steam quantity available. The change in speed, when changing from high-pressure steam to low-pressure steam or *vice versâ*, must therefore be as small as possible. These conditions were first realised by Professor Rateau, who invented a governor fulfilling these conditions (see English Patent No. 3822, 1905), and which is now applied by nearly all the manufacturers of mixed-pressure turbines.

Fig. 32 shows a sectional diagram of the mixed-pressure governor made by the British Westinghouse Company in accordance with Professor Rateau's patents. Its operation is as follows:—

The low-pressure steam main is in communication with the under side of the spring-balanced piston A. When enough low-pressure steam is available, the steam pressure in the low-pressure main is above normal, and forces piston A to the top position, so that the relay valve H connects the top of piston B with the oil drain pipe. This causes piston B to rise also to the top position, until relay valve H returns to its mid position.

Under these circumstances the low-pressure valve is under the control of the speed governor only. When, for instance, the output required increases, the speed of the turbine will decrease. The lever P rotating in the direction of the arrow takes up a position dependent upon the new speed. In doing so the relay valve K is lowered from its mid position admitting oil under pressure beneath the power piston C. C rising lifts the low-pressure valve by means of lever N, the high-pressure valve being held down by the spring D.

When the available low-pressure steam quantity decreases below the required amount, the pressure in the low-pressure main decreases also and causes piston A to descend, and by lowering the relay valve H from its mid position admits oil pressure above B. Piston B descends and with it stop S, which partially closes the low-pressure valve and simultaneously lifts the high-pressure valve by means of the floating lever N without affecting the position of piston C, *i.e.*, without affecting the speed of the turbine.

The motion continues until H is again in mid position and the low-pressure valve lift adjusted so as to admit just the low-pressure steam quantity available without the pressure in front of the valve decreasing below atmospheric pressure. The low-pressure valve is now only under the control of the steam pressure in the low-pressure main. Any

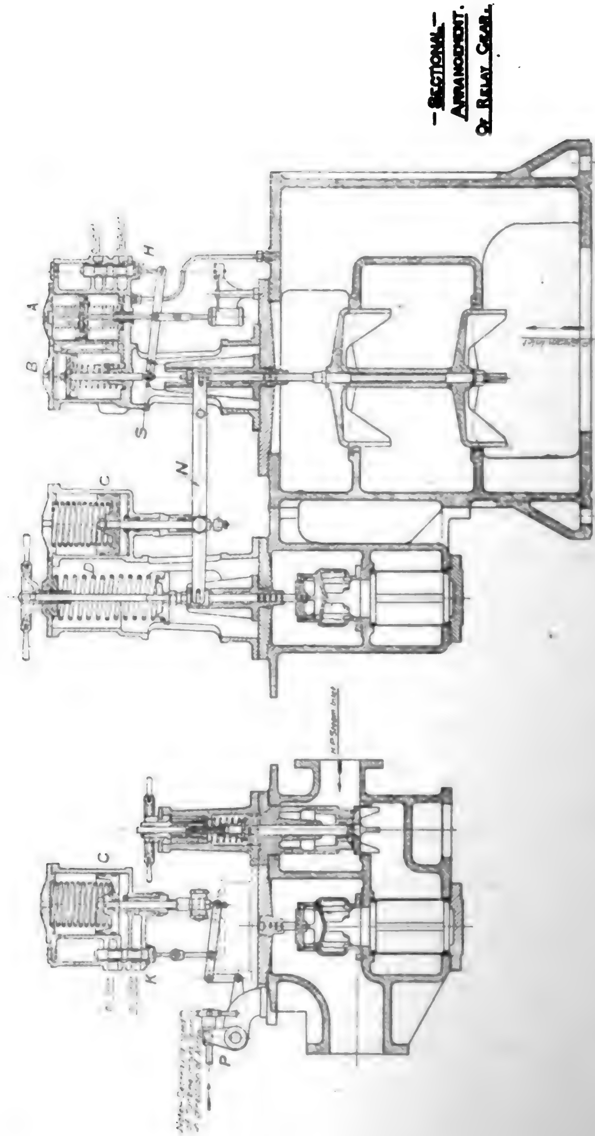


Fig. 32.—Governor for Mixed-pressure Turbines.

further increase of the load and decrease in the speed of the turbine does not change the position of the low-pressure valve, but opens only the high-pressure valve.

Changes of outputs or low-pressure steam quantities of the opposite nature to those considered above result in a reverse series of operations.

Although it is only five years since the first mixed-pressure turbine was installed in this country for the Gloucester Railway Wagon and Carriage Company by the British Westinghouse Company, its development has been very rapid during the last two years. The present importance of the mixed-pressure turbines for this country is best illustrated by the fact that the number ordered during the last three years is practically equal to the number of high-pressure turbines, whereas of low-pressure turbines only about one-eighth of this number has been ordered.

It is interesting to compare the two main turbine types, the drum types and disc types when designed as low-pressure or mixed-pressure turbines.

The only factor we need to consider is the maximum output which can be obtained from the low-pressure part of these turbines.

The steam consumption of low-pressure turbines is about double that of high-pressure turbines, which means that a low-pressure turbine has to deal with twice the steam quantity of a high-pressure turbine of the same output, or the maximum output of a low-pressure turbine is only half that of a high-pressure turbine assuming the outlet velocity of the last rows of blades is the same for both high-pressure and low-pressure turbines. As, however, the available heat drop of a low-pressure turbine is only about half that of a high-pressure turbine, the leaving losses when expressed in per cent. of the heat drop appear twice as high. It is therefore of great importance to keep these leaving losses as low as possible. Diagram 23, page 806, can be used for the approximate calculation of maximum outputs of the low-pressure and mixed-pressure turbines, when taking the maximum outputs to be half and the leaving losses to be double those indicated.

It shows, for instance, that for impulse turbines running at 3,000 revs. per minute and a leaving loss of 5 per cent. the maximum output is only 2,300 k.w. at 27½ in. vacuum,

or— 1,900 k.w. at 28 in. vacuum,

or— 1,600 k.w. at 28½ „ „

whereas for drum turbines the leaving losses for the same outputs would be 20 per cent., which in most cases would be far too high, so that a double-flow turbine would be necessary.

From this it is clear that in the case of low-pressure turbines the maximum outputs obtainable depend more on the turbine than the alternator, which is, of course, the reverse of that we found in the case of high-pressure turbines.

4. *Back-pressure Turbines.*—Back-pressure turbines exhaust against

a back pressure which is above atmospheric pressure. Turbines run non-condensing and exhausting into free atmosphere are also included in this class.

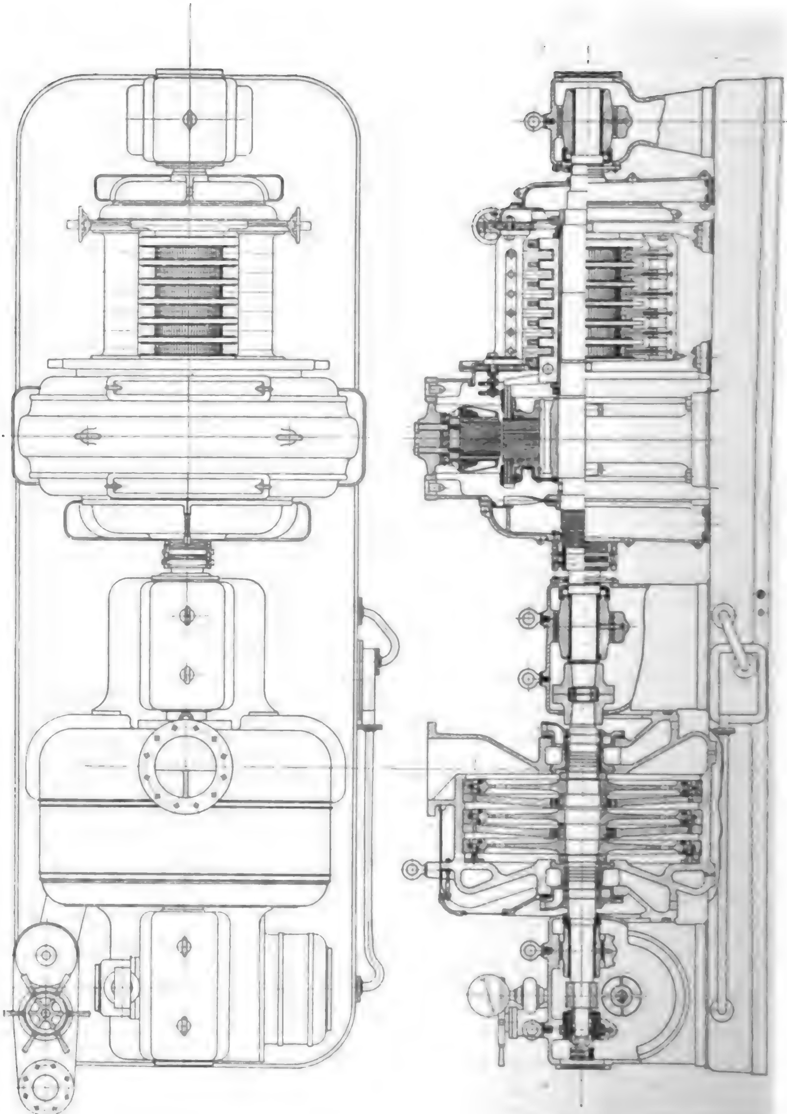


FIG. 33.—Back-pressure Turbine, Ship Lighting Set. The British Westinghouse Company, Ltd.

The exhaust steam from back-pressure turbines is generally used for heating purposes, as, for instance, in ships for heating the feed water, or in mills for heating water in open pans, or in salt works for

evaporating brine. Fig. 33 represents a low-speed ship-lighting set 400 k.w. running at 1,500 revs. per minute driving a direct-current generator, and exhausting against 20 lbs. per square inch absolute back pressure. The exhaust steam is used for heating the feed water. The small output at a very low speed and the light weight required made it necessary to use velocity wheels.

The governing of these turbines may differ according to the conditions prevailing. When all the steam is required for heating purposes independent of the load, an ordinary speed governor is used, opening or closing a high-pressure throttle valve according to the load required. When, on the other hand, the turbine is required to work in parallel with other engines, and is intended to utilise only that amount of steam required for heating purposes, it need not be provided with a speed governor at all, the steam being controlled by the pressure in the heating steam pipe. If more heating steam is required the pressure in the heating steam main decreases, and this change of pressure can be used to open the governor valve in a similar manner to that used for reducing valves. Fig. 34 shows an arrangement where either of the two methods can be used, governing by mechanical governor or by the pressure in the heating main.

Neither of the two methods are quite satisfactory in all cases. If, in the first case, more load is required than that obtainable from the heating steam available, steam must be passed through the turbine and blown into atmosphere. This represents a great loss, as this steam could be utilised in a low-pressure turbine. The second method is absolutely satisfactory in this respect, but it is necessary that it be run in parallel with other engines, the load of which is changed according to the heating steam quantity required.

An absolutely satisfactory arrangement can be obtained by the use of the—

5. *Reducing Turbines.*—In case the load of the turbine is more than that obtainable from the heating steam quantity required the surplus steam is by-passed to low-pressure wheels which are fixed on the same shaft and placed in the same cylinder. The sectional blading arrangement, and the governing arrangement of a reducing turbine are shown in Fig. 35. This drawing refers to a 1,500-k.w. turbine running at 3,000 revs. per minute, and supplying normally 47,000 lbs. of steam per hour at 16 lbs. per square inch absolute back pressure for salt works.

Governing arrangements for reducing turbines have already been patented in this country in 1892 by T. Murrie (Patent No. 14013/1892). Patents on the same subject have been taken out in Germany by E. Mennig and G. D. Picard (Engl. No. 18932/1903), and P. Beck (No. 139013/1902).

The governing arrangement for the turbine shown is similar to the mixed-pressure governor described above. The heating steam main is in communication with the underside of the spring-balanced piston N, which operates the low-pressure valve M by relay valve S and

1. **Turbine running in parallel with other Machines.**—*Speed Governor does not come into action. Point A will serve as fulcrum being in position A''.*

The load on the Turbine is fixed by the requirement of heating steam. If B is in position B' no heating steam is required. Turbine runs at no load. If B is in position B'' the maximum quantity of heating steam is required, the turbine runs at full load. Should the demand of heating steam be still larger than the amount corresponding to the maximum load of the turbine, the reducing valve R will automatically open and allow live steam to go to the heaters.

2. **Turbine running by itself.**—*Speed Governor is in action. Point B will serve as fulcrum being in Position B'. The Steam Piston B is kept in position B' by means of the handwheel W. If more heating steam is required than the Turbine supplies, the reducing valve R admits live steam to the heaters. If less heating steam is required than the Turbine exhausts, the surplus steam would pass through the relief valve to atmosphere.*

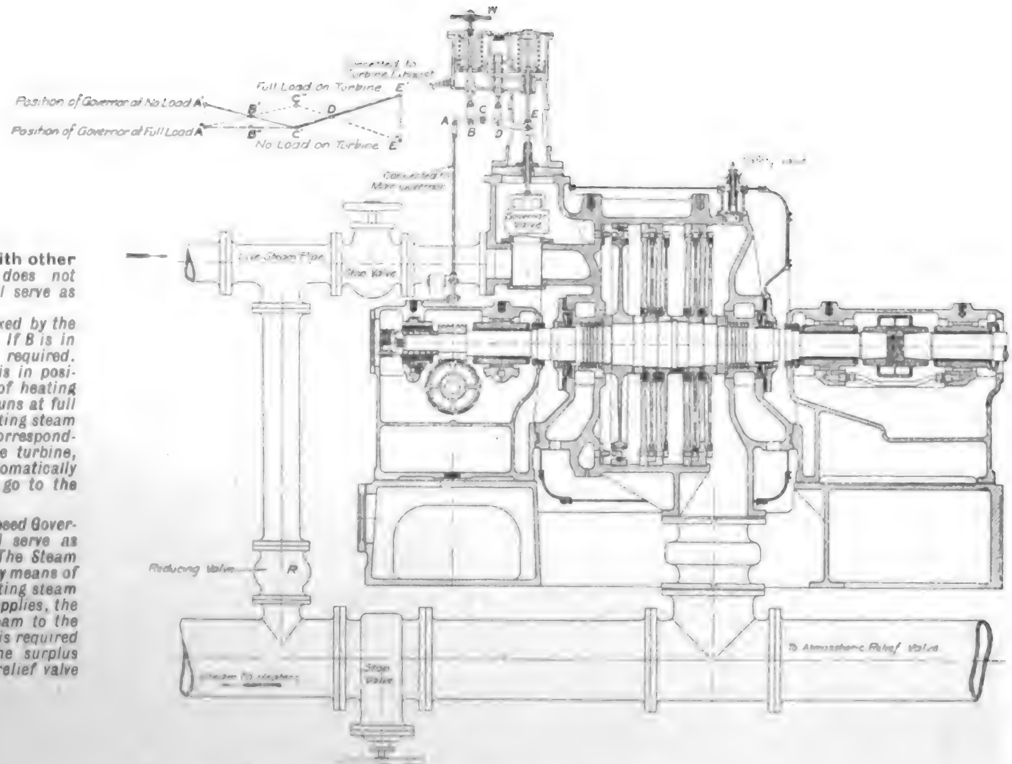


FIG. 34.—Back-pressure Turbine Governor.

power piston R, admitting steam to the low-pressure turbine. The high-pressure valve is controlled both by the position of the low-pressure valve and the speed governor through the horizontal lever connecting the two governor valves.

When the turbine is running at a certain load and the heating steam quantity decreases, the pressure rise in the heating steam main will cause piston R to rise and consequently the low-pressure valve to

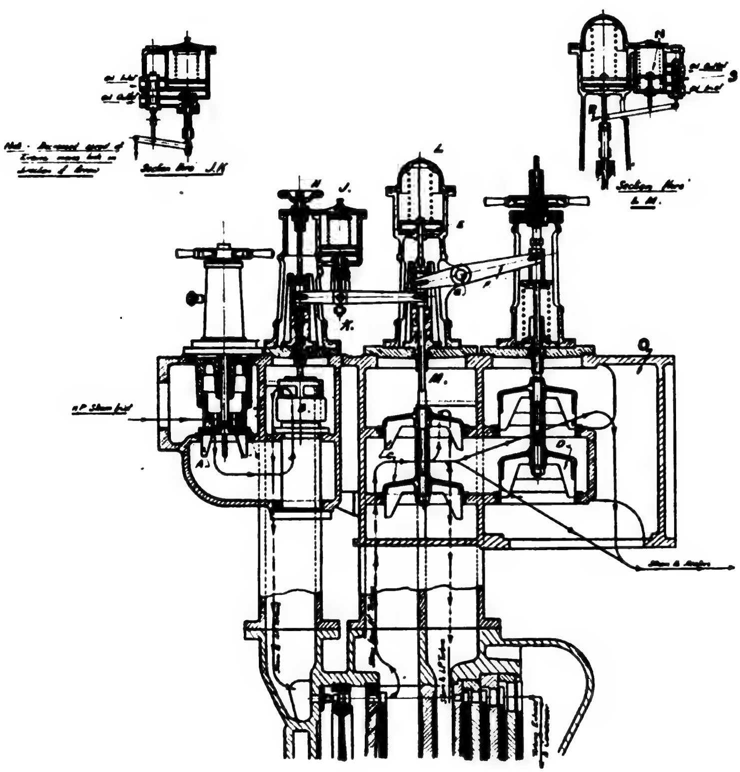


FIG. 35.—Reducing Turbine Governor.

open, and simultaneously the high-pressure valve to close. More power will be developed on the low-pressure side, and less on the high-pressure side. The load is kept constant without appreciably affecting the position of piston JK and consequently the speed of the turbine.

On the other hand, when the output increases the decrease in speed causes the piston J K to rise. The high-pressure valve will first be opened, and afterwards the low-pressure valve, on account of increasing back pressure. Thus both high-pressure and low-pressure valves

are automatically adjusted for the larger load without any change in the heating steam quantity.

Variation in the outputs, or in the heating steam quantity of the opposite nature to those considered above, result in a reverse series of operations.

In order to obtain automatically overloads with small quantities of heating steam, it is necessary to increase the pressure in front of the low-pressure wheels, so that a correspondingly increased steam quantity is passed through the low-pressure turbine. This is done automatically by lever F, which is operated by the low-pressure valve as soon as the latter is full open. The same arrangement may, under certain circumstances, be used for full load, the principle being to throttle always the smaller quantities, either the low-pressure steam or the heating steam, in order to secure the highest possible economy at all loads.

VIII. Improvement in Economy of Steam Turbines.

In Tables III., IV., V., VI., and VII., the most important test results obtained during the last five years on high-pressure, low-pressure, and mixed-pressure turbines are given together with the efficiencies of the turbines and generators.*

The full-load consumptions and total efficiencies of the most important turbines are given in the following list :—

No.	Manufacturer.	Year of Test.	Kilo-watts.	Revs. per Minute.	Lbs. per Kilowatt-hour.	Total Efficiency.
1	A.E.G.	1906	3,000	1,500	12·75	63·8
2	C. A. Parsons	1907	3,500	1,200	13·35	62·7
3	Westinghouse Machine Co....	1907	7,500	750	15·00	66·3
4	Brown-Boveri & Co.... ...	1907	3,500	1,360	13·70	64·8
5	Escher, Wyss & Co.	1908	5,000	1,000	15·17	63·1
11	A.E.G.	1909	4,000	1,500	11·92	63·8
12	El. Maschinenfabrik	1910	3,500	1,500	14·07	64·8
14	Maschinenfabrik Augsburg-Nürnberg	1910	2,500	1,500	15·50	64·5
18	B.T.H.	1911	3,000	1,500	15·96	64·7
21	Escher Wyss	1910	4,000	1,000	13·30	64·4
22	Escher Wyss	1910	2,000	3,000	13·03	66·0
25	Oerlikon	1911	3,000	1,500	11·62	64·1
26	British Westinghouse ...	1911	3,000	1,500	13·72	63·9
27	British Westinghouse ...	1911	5,000	1,500	13·00	67·9
28	Richardson Westgarth ...	1910	6,250	1,200	11·90	68·4

From this list it will be seen that the steam consumption has been

* These tables have been completed and recalculated in accordance with the entropy diagrams based on the latest Munich results by Mr. M. Helfenstein.

Generator Efficiency.	Be Gove Va i' B.T
Per Cent.	
83·0	45
89·0	44
92·5	43
94·5	41
94·5	41
95·0	40
95·0	40
94·9	40
91·0	40
lbs./hr.	39
	38
95·0	34
94·6	38
93·0	39
89·0	39
lbs./hr.	38
87·0	34
92·5	34
94·2	33
95·3	35
94·0	36
91·3	38
86·0	40
94·3	36
lbs./hr.	39
	39
92·5	40
90·7	41
87·0	41
77·6	43
92·5	39

Actual Steam Consumption Lbs./k.w.-hour.
19·15
16·15
15·50
16·15
14·60
15·42
14·60
14·10
11·70
11·95
11·92
14·07
14·12
14·40
14·74
14·30
14·60
15·67
19·31
15·50
13·55
13·10
18·76
16·86
15·70
15·74
15·96
15·90
17·10
17·46
18·05
19·30

TABLE V.

…gh-pressure Tu…

…r Governor Valve.		E… Pr… I… Va…	Remarks.
…ure …. in …ge.	Temperature t_1 °F.		
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	—
	—	2	…ut out at half load.
	—	2	—
	—	2	—
3	—	28	—
0	—	28	—
3	—	28	—
5	—	27	—
0	—	27	—
5	—	28	—
0	—	28	—
0	—	28	—
0	—	28	—

VI.

Turbines.

...er Governor Valve.		Exh Pres t' Inc Vac...	Remark.
...ure ...in. ...ge.	Temperature t_1 °F.		
...	—	29·...	—
...	—	29·...	—
...	—	29·...	—
...o	525·0	28·...	—
...o	530·0	28·...	—
...o	527·0	28·...	—
...o	544·0	28·...	—
...o	539·5	28·...	—
...	494·0	28·...	Excited.
...bs.	301·5	28·...	...urbine alone.

TABLE VII.

nd Mixed-press

ter Governor Valve.		E P	Remarks.
sure 1 q. in. ge.	Temperature t_1 °F.	V	
—	—		g as high-pressure e.
—	—		
—	—		
—	—		g as low-pressure e.
—	—		
—	—		
	—		
·45	Absolute.		g as L.P. turbine. m load on low-pressure is 1,800 k.w.
·95			
·77			
·46	—		g as high-pressure e.
·60	—		g as L.P. turbine.
·00	Abs.		
·00	Absolute.		g as low-pressure e.
·00			
·17			ut out.
·60	—		g as high-pressure e.
·60	—		
·10	—		
·90	Absolute.		low-pressure turbine.
·40			
·22			

improved from 12·75 lbs. per kilowatt-hour in 1906 to 11·6 lbs. per kilowatt-hour in 1911; and the total efficiency—

$$\frac{\text{Actual output on generator}}{\text{Mechanical equivalent of heat drop according to adiabatic expansion}}$$

from 63·8 per cent. in 1906 to 66·3 per cent. in 1907, and 68·4 per cent. in 1910. This figure has not been improved upon in 1911.

The best efficiency on mixed-pressure turbines running on low-pressure steam has been obtained on a 1,000-k.w. turbine running at 3,000 revs. per minute, made by the British Westinghouse Company. The efficiency realised in this case was 69·8 per cent.

IX.—Change of Steam Consumption with varying Steam Conditions.

The efficiency of a steam turbine is the ratio :—

$$\frac{\text{Actual work done on turbine shaft}}{\text{Mechanical equivalent of heat drop according to adiabatic expansion}}.$$

This ratio is referred to wherever efficiency is mentioned in the following discussion.

In order to compare the merits of different steam turbines, the efficiencies as obtained above are usually calculated and compared.

This, however, does not provide a rational basis of comparison, as the efficiency of a turbine is itself dependent upon the steam conditions. It is well known, for instance, that the efficiency increases with the superheat.

For this reason the author has adopted standard steam conditions to which the performances of all turbines can be reduced by applying proper corrections.

These standard conditions are :—

For high-pressure turbines, 180 lbs. per square inch gauge; pressure, 150° F. superheat, 28 in. vacuum (30 in. Bar.).

For low-pressure turbines, 16 lbs. per square inch absolute pressure, 0° F. superheat, 27½ in. vacuum (30 in. Bar.).

1. *Corrections for Turbines designed for Particular Condition: (a) Superheat.*—According to our present knowledge the corrections to be made for superheat are independent of steam pressure and vacuum, and are therefore the same for high-, low-, and approximately for back pressure turbines.

The corrections are as follows :—

Between—

0–100° F. superheat, 1 per cent. improvement of steam consumption for every 10° F. superheat.

100–200° F. superheat, 1 per cent. improvement of steam consumption for every 12° F. superheat.

200–300° F. superheat, 1 per cent. improvement of steam consumption for every 14° F. superheat.

The efficiency increases with the superheat, and consequently the actual is larger than the theoretical correction which is calculated from the variations of the available heat drop in adiabatic expansion.

Fig. 36 shows plotted the actual superheat corrections for high-pressure turbines together with the change of efficiency, and the

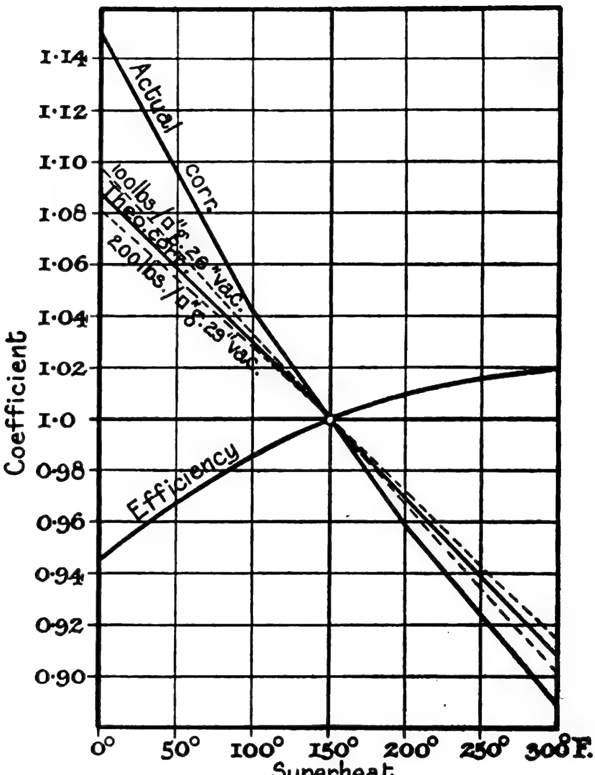


FIG. 36.—Superheat Corrections for High-pressure Turbine designed for Superheat.

mean theoretical correction for steam conditions varying between the limits:—

100 lbs. per square inch gauge pressure, 26 in. vacuum.
200 „ „ „ 29 „ „

Fig. 37 shows plotted similar values for low-pressure turbines for steam conditions, varying between the limits:—

14 lbs. per square inch absolute pressure, 26 in. vacuum.
18 „ , „ 29 „ „

The improvements in efficiency may be taken as :—

4·25 per cent. better efficiency at 100° F. superheat, than for dry saturated steam,

6·75 per cent. better efficiency at 200° F. superheat than for dry saturated steam,

7·5 per cent. better efficiency at 300° F. superheat than for dry saturated steam,

from which the futility of comparing the efficiencies of turbines without a knowledge of the superheat is apparent.

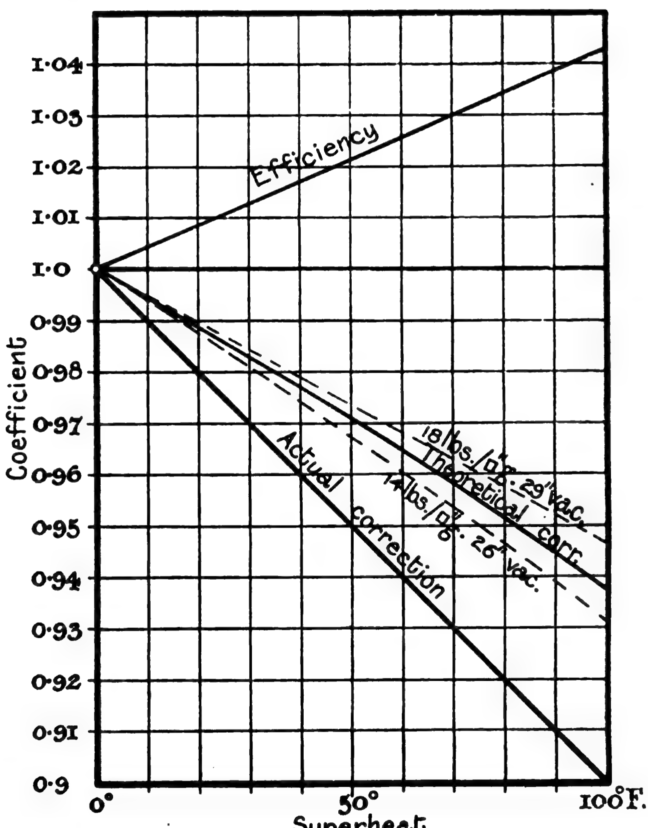


FIG. 37.—Superheat Corrections for Low-pressure Turbine designed for Superheat.

The corrections given have been deduced from a large number of tests made on impulse turbines; they are probably too large for pure Parsons turbines, which are unable to utilise high superheat to the same extent as impulse or impulse reaction turbines.

Tests have shown that *when the steam is wet* the efficiency is reduced. Assuming that the efficiency follows a continuous curve for superheated and wet steam when plotted with entropy as a basis, the efficiency will change by 1 per cent. for each 1 per cent. variation in wetness. It follows therefore that the steam consumption measured as condensed water will be 2 per cent. higher for each 1 per cent. increase in moisture.

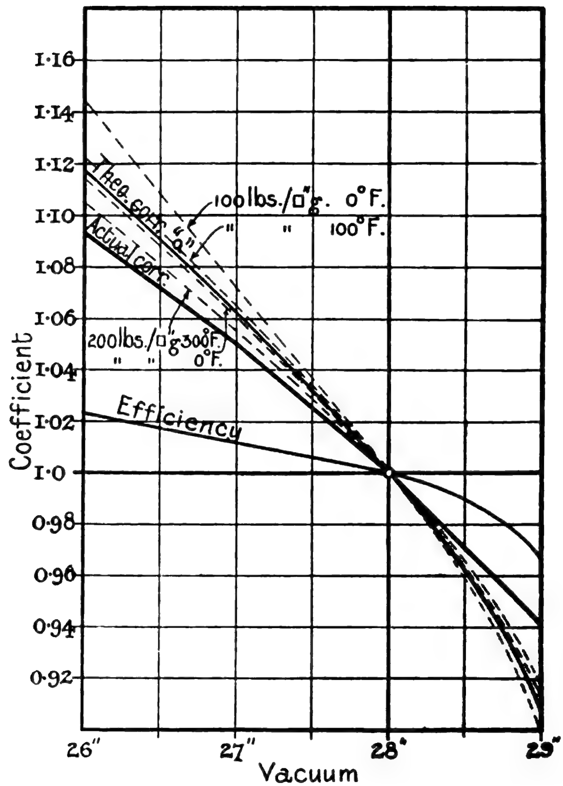


FIG. 38.—Vacuum Corrections for High-pressure Turbine designed for Vacuum.

(*b*) *Vacuum.*—The efficiency of a high-pressure turbine using and designed to use a very high vacuum will not be so good as that of a turbine of quite similar type, having the same number of stages, but designed to utilise a lower vacuum.

The difference will be slightly larger for drum than for disc turbines, as the latter can be designed to use a higher vacuum to greater advantage than the former.

The corrections for high-pressure turbines are given in Fig. 38.

The average theoretical corrections obtained by considering the adiabatic heat drop available are plotted in curve A and may be taken as :—

5 per cent. improvement of steam consumption for 1 in. between 26 in. and 27 in vacuum.

6 per cent. improvement of steam consumption for 1 in. between 27 in. and 28 in. vacuum.

7·75 per cent. improvement of steam consumption for 1 in. between 28 in. and 28½ in. vacuum.

11·5 per cent. improvement of steam consumption for 1 in. between 28½ and 29 in. vacuum.

The actual improvement which can be obtained with the present design of impulse turbine is :—

4 per cent. improvement of steam consumption for 1 in. between 26 in. and 27 in. vacuum.

5 per cent. improvement of steam consumption for 1 in. between 27 in. and 28 in. vacuum.

6 per cent. improvement of steam consumption for 1 in. between 28 in. and 29 in. vacuum.

According to these figures the efficiencies of equivalent high-pressure turbines with the same number of stages using and designed to utilise different vacua would be :—

1	per cent. better efficiency at	26	in. than at	27	in.
1	,, ,,	27	,, ,,	28	,,
1	,, ,,	28	,, ,,	28½	,,
2·5	,, ,,	28½	,, ,,	29	,,

These figures represent a very fair average for any steam conditions between the limits :—

Steam pressure, 100 lbs. per square inch gauge to 200 lbs. per square inch gauge.

Superheat 0° F. to 300° F.

Whereas the superheat correction is nearly independent of the other steam conditions, the vacuum correction depends to a great extent upon the steam pressure, and is very much larger for low-pressure turbines, the corrections for which are given in Fig. 39.

The average theoretical corrections for these are :—

12 per cent. improvement of steam consumption for 1 in. between 26 in. and 27 in.

13·75 per cent. improvement of steam consumption for 1 in. between 27 in. and 28 in.

17 per cent. improvement of steam consumption for 1 in. between 28 in. and 28½ in.

22·5 per cent. improvement of steam consumption for 1 in. between 28½ in. and 29 in.

The actual improvements which can be obtained with the present design of low-pressure impulse turbine of similar construction, but increased number of stages for higher vacuum, are:—

11·5 per cent. improvement of steam consumption for 1 in. between 26 in. and 27 in. vacuum.

13 per cent. improvement of steam consumption for 1 in. between 27 in. and 28 in. vacuum.

14·5 per cent. improvement of steam consumption for 1 in. between 28 in. and 29 in. vacuum.

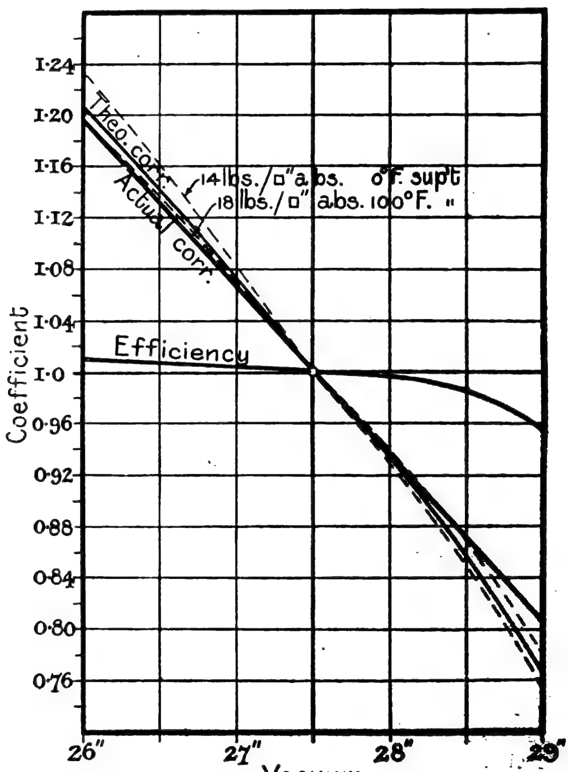


FIG. 39.—Vacuum Corrections for Low-pressure Turbine designed for Vacuum.

According to these figures low-pressure turbines using and designed to utilise different vacua give efficiencies as follows:—

0·5	per cent. better efficiency at	26	in.	than at	27	in.	vacuum.
0·7	"	27	"	"	28	"	"
1·0	"	28	"	"	28½	"	"
3·5	"	28½	"	"	29	"	"

The corrections given represent a very fair average for any steam conditions between the limits :—

14 lbs. per square inch absolute	... ...	0° F.
18 " " "	... ...	100° F.

(*c*) *Pressure.*—The efficiency which can be obtained with turbines having the same number of stages depends also, but in a lesser degree, upon the steam pressure.

When the steam pressure is low not only are the leakage, ventilation, and friction losses in the turbine smaller, but the blading efficiency increases as the total heat drop decreases.

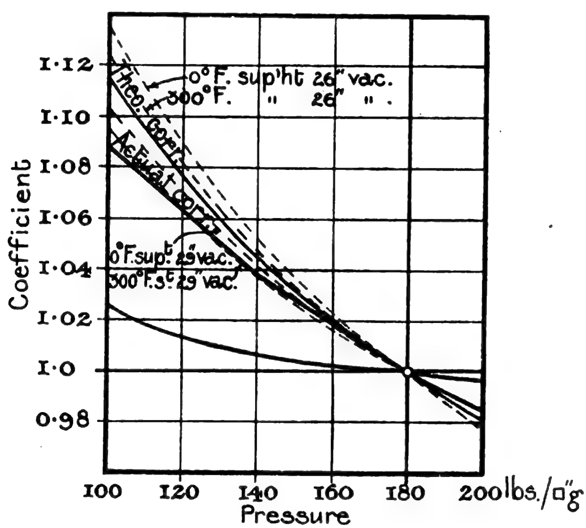


FIG. 40.—Pressure Correction for High-pressure Turbine designed for the Pressure.

The corrections for pressure in the case of high-pressure turbines are shown in Fig. 40.

The average theoretical corrections are as follows :—

2 per cent. improvement in steam consumption for 10 per cent. increase of pressure between 100 and 140 lbs. per square inch gauge.

1·95 per cent. improvement in steam consumption for 10 per cent. increase of pressure between 140 and 180 lbs. per square inch gauge.

1·90 per cent. improvement in steam consumption for 10 per cent. increase of pressure between 180 and 200 lbs. per square inch gauge.

The actual improvements in steam consumption which can be obtained with the present design of impulse turbine are:—

1·5 per cent. improvement in steam consumption for 10 per cent. increase of pressure between 100–200 lbs. per square inch gauge.

According to these figures equivalent high-pressure turbines having

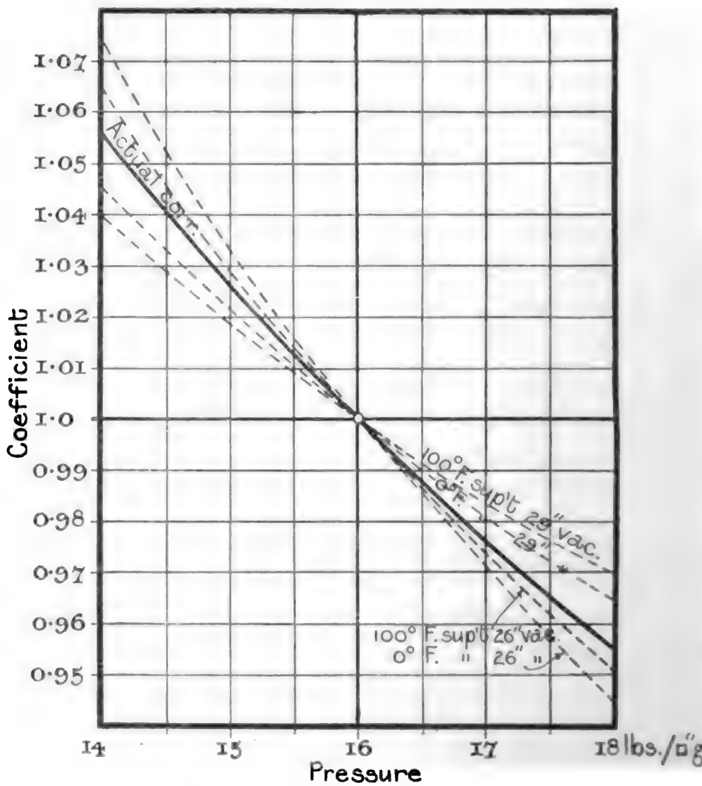


FIG. 41.—Pressure Correction for Low-pressure Turbine designed for the Pressure.

the same number of stages, using and designed to utilise different pressures, would give improved efficiencies as follows:—

0·4 per cent. better at 180 lbs. per square inch than at 200 lbs. per square inch gauge.

1·0 per cent. better at 140 lbs. per square inch than at 180 lbs. per square inch gauge.

1·6 per cent. better at 100 lbs. per square inch than at 140 lbs. per square inch gauge.

These corrections are a very fair average for any steam conditions between 0° F. superheat, 26 in. vacuum, and 300° F. and 29 in. vacuum.

For low-pressure turbines the consumption correction is plotted in Fig. 41.

The range of pressure met with in low-pressure turbines is so small that the pressure correction for thermo-dynamic efficiency is negligible.

The average consumption correction is as follows :—

4 per cent. improvement for 10 per cent. increase of pressure between 14–18 lbs.

These figures may be taken as a fair average between the limiting steam conditions, 0° F. superheat, 26 in. vacuum, and 100° F. superheat, 29 in. vacuum.

The corrections we have already considered refer to the steam consumptions of turbines utilising steam conditions, for which they have been specially designed, and are of the greatest importance to the purchaser when fixing the steam conditions under which turbines have to work.

In addition to these, however, we have to consider :—

2. *Corrections for Turbines running under Conditions different from those for which they have been Designed* : (*a*) *Superheat.*—When a turbine designed for definite conditions of load, pressure, superheat, and vacuum is tested at a specified load, a rise in superheat will affect the pressure in front of the nozzles because :—

1. The steam consumption decreases.
2. The specific volume of the steam increases.

The steam quantity flowing through a turbine is given by the following formulæ :—

$$G = K \sqrt{\frac{p}{v}} \text{ kg. or lbs./sec.} \quad \ldots \ldots \quad (24)$$

Where—

K = a constant for the turbine.
p = pressure in front of the nozzles.
v = specific volume of the steam in front of the nozzles.

But the law $p\,v = R\,T$ is approximately true.

Where—

T = the absolute temperature of steam.
R = constant of steam.
= 47·1, if p is in kg./m.^{2} and T is the absolute temperature Centigrade.
= 85·5, if p is in lbs./sq. in. and T is absolute temperature Fahrenheit.

Therefore—

$$\frac{p}{v} = \frac{p^2}{RT} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

from (24)—

$$G = \frac{kp}{\sqrt{RT}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

or—

$$p = \frac{G}{K}\sqrt{RT} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

In practice, the temperature varies between 700° F. and 1,000° F. absolute.

Now the improvement in steam consumption and therefore the decrease in G is 1 per cent. for every 10–14° F. increase in superheat, and with the same change of superheat $\sqrt{T}$ increases by 0·7 per cent. Thus the decrease of pressure before the nozzle will be 0·3 per cent. for every 1 per cent. decrease in steam consumption.

As, however, 10 per cent. decrease in pressure only increases the steam consumption by 1½ per cent. for high-pressure turbines or 4 per cent. for low-pressure turbines, the additional change of consumption due to increase of pressure before the nozzles can be safely neglected.

The superheat corrections for steam consumptions measured at certain specified full loads, or partial loads, are therefore the same as those already given for turbines designed for the different superheats, *i.e.* :—

1 per cent. improvement of steam consumption for every 10° F. superheat between 0–100° F.

1 per cent. improvement of steam consumption for every 12° F. superheat between 100–200° F.

1 per cent. improvement of steam consumption for every 14° F. superheat between 200–300° F.

It will be apparent that the difference in turbines of the same output and designed for various superheats is negligible. For the reasons as stated above the corrections for wetness also remain the same as those given.

(*b*) *Vacuum.*—When a turbine designed for a certain load, superheat, pressure, and vacuum is tested at a specified load, an improvement in the vacuum will affect the pressure in front of the nozzles, because the steam quantity going through the turbine becomes smaller.

If, for instance, an improvement of the vacuum from 27 in. to 28 in. causes a decrease in steam consumption of 5 per cent. the steam pressure in front of the nozzles will also drop by 5 per cent.

The turbine will now be 5 per cent. too large for these conditions and the steam will be throttled to a greater extent than if the turbine had been designed for 28 in. vacuum. The improvement due to vacuum

will therefore be smaller than that already given for turbines designed for various vacua.

In the case already considered 5 per cent. decrease in pressure would, for high-pressure turbines, decrease the improvement due to vacuum by ⅓ per cent.

The improvement will be further decreased because the efficiency of the last stages, being designed for 27 in. and working with 28 in., will be inferior to that of stages designed to deal with the larger steam volumes at 28 in. vacuum.

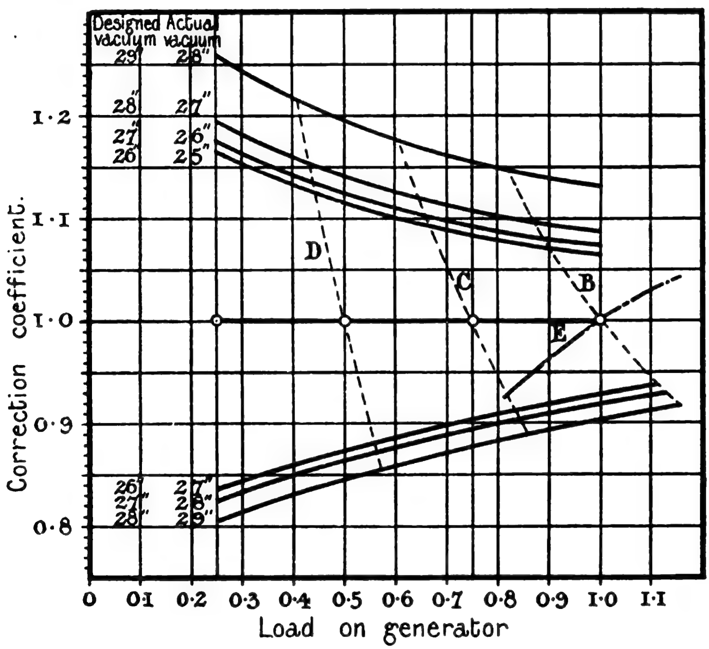


FIG. 42.—Vacuum Correction for Low-pressure Turbines.

From this it will be apparent that the decrease in consumption of a turbine for a certain range of vacuum will depend upon the vacuum for which the turbine has been designed.

The correction for partial loads becomes larger for two reasons :—

(*a*) As the available heat drop becomes less the change due to vacuum is relatively larger.

(*b*) As the total weight of steam flowing through the turbine becomes less, the blading of the last stages is better able to cope with the increased volume due to increased vacuum.

For these reasons the corrections will be still larger for mixed-pressure turbines where the low-pressure part is too large for the steam quantity used when running on high-pressure steam.

Table VIII. gives the vacuum corrections for high-pressure turbines and mixed-pressure turbines working with high-pressure steam. In calculating these allowance has been made for the additional corrections considered above.

For low-pressure turbines the difference between the corrections given for turbines designed for various vacua, and for turbines working with vacua other than for which they were designed, is still greater. If, for example, an improvement of vacuum from 27 in. to 28 in. decreases the steam consumption by 13·75 per cent., the steam pressure in front of the first guide blades falls by 13·75 per cent.

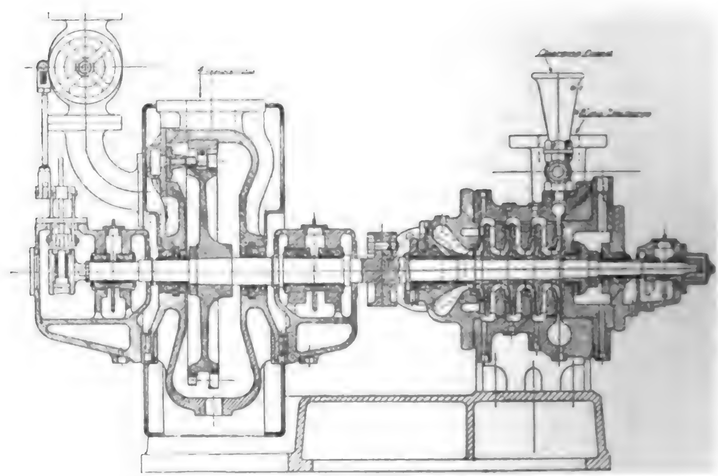


FIG. 44.—Turbine-driven Boiler Feed Pump. The British Westinghouse Company, 1911.

As a pressure decrease of 10 per cent. on low-pressure turbines increases the steam consumption by 4 per cent. the correction is reduced from 13·7 per cent. to about 9·5 per cent.

The actual corrections for different generator loads of turbines designed for 26 in., 27 in., 28 in., and 29 in. vacuum are plotted in Fig. 42 for 1 in. change in vacuum above or below that for which the turbine is designed.

When a turbine designed for a given vacuum is run at a lower one, it will not supply the designed full load with the "full-load" nozzles and the designed pressure before the nozzles. The total steam quantity remains the same, but since the available heat drop is reduced the work done will also be reduced.

If, for example, a turbine is designed for 26 in. and is run at 25 in.

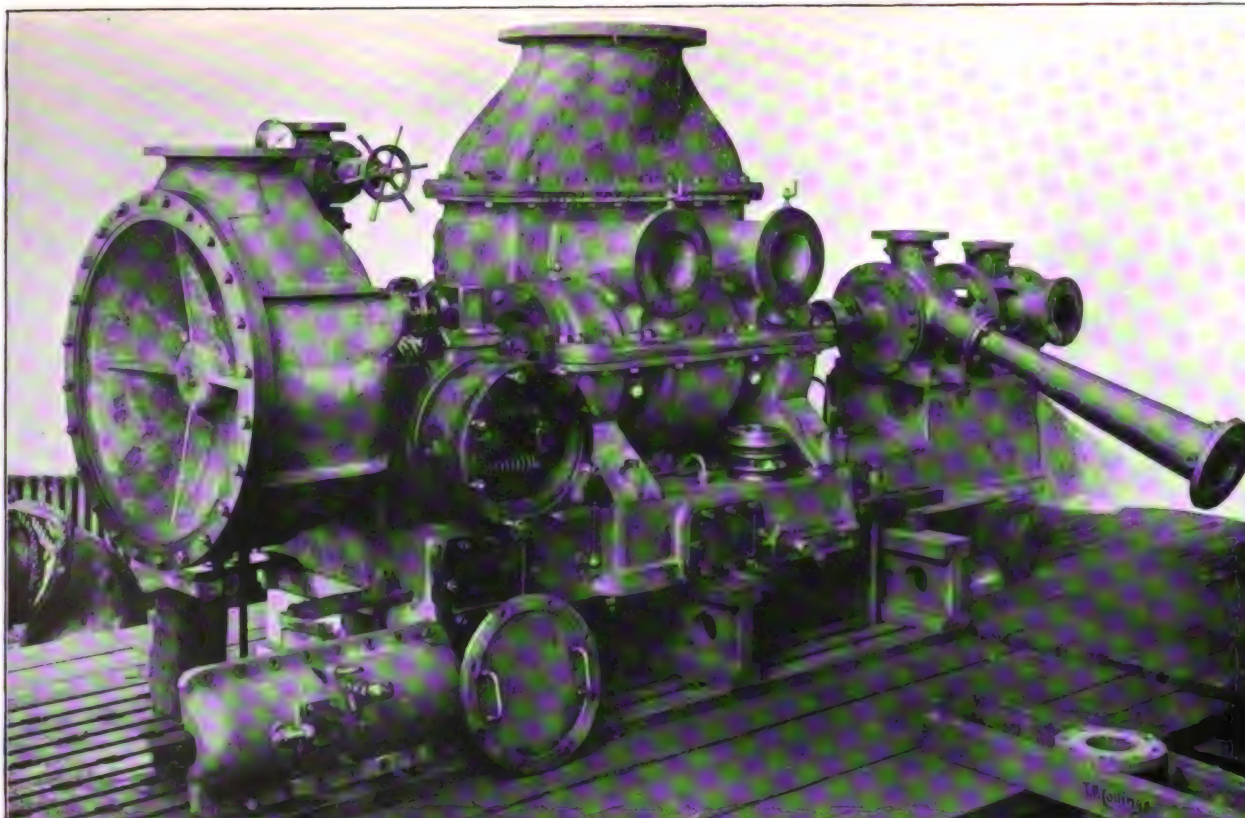


FIG 43.—Turbine-driven Auxiliary Pumps. The British Westinghouse Company, 1910.

TABLE VIII.

Vacuum Correction for High-pressure and Mixed-pressure Turbines.

Designed Steam Conditions.			Theoretical Correction for 1 in. Vacuum Variation.	Actual Correction for 1 in. Vacuum Variation.								Range of Vacuum Variation. Inches.
Pressure Lbs., sq. in. g.	Superheat ° F.	Vacuum. Inches.		H.P. 4/4 Load	M.P. 4/4	H.P. 3/4	M.P. 5/4	H.P. 1/2	M.P. 4/4	H.P. 1/4	M.P. 1/2	
180	150	26	4·4	3·0		3·8		4·8		6·5		24–26–27
		27	5·5	3·7		4·6		5·6		7·6		25–27–28
		28	7·0	5·1		6·2		7·5		9·7		26–28–28½
		29	10·3	7·5		8·5		10·2		12·8		28–29
140	150	26	4·7	3·2		4·2		5·0		6·9		24–26–27
		27	5·8	3·9		4·8		5·9		8·0		25–27–28
		28	7·3	5·3		6·3		7·8		10·2		26–28–28½
		29	11·0	7·8		8·8		10·7		13·5		28–29
100	150	26	5·0	3·5		4·5		5·5		7·5		24–26–27
		27	6·2	4·2		5·3		6·4		8·7		25–27–28
		28	7·9	5·7		6·6		8·4		10·9		26–28–28½
		29	11·9	8·5		9·5		11·5		14·5		28–29
75	150	26	5·4	3·8		4·8		6·0		8·0		24–26–27
		27	6·6	4·6		5·6		6·9		9·4		25–27–28
		28	8·5	6·1		7·1		9·0		11·6		26–28–28½
		29	12·7	9·1		10·3		12·3		15·5		28–29
50	150	26	5·9	4·3		5·2		6·7		8·7		24–26–27
		27	7·2	5·0		6·0		7·7		10·3		25–27–28
		28	9·2	6·6		7·7		9·9		12·6		26–28–29
		29	13·5	9·9		11·3		13·3		16·8		28–29

Partial loads are expressed as fractions of the full load for which turbine is designed.
The correction is to be made when the turbine is run on a vacuum other than that for which it was designed.
The theoretical correction is given for 150° F. superheat.
The actual correction given for various loads can be used for any superheat between saturation and 300° F.

vacuum, the maximum load at this vacuum will only be 90 per cent. of the designed full load at 26 in. vacuum. The designed full load can, however, be obtained by raising the pressure before the nozzles.

The maximum loads which can be obtained with a vacuum 1 in. above or below that for which a turbine is designed, provided the

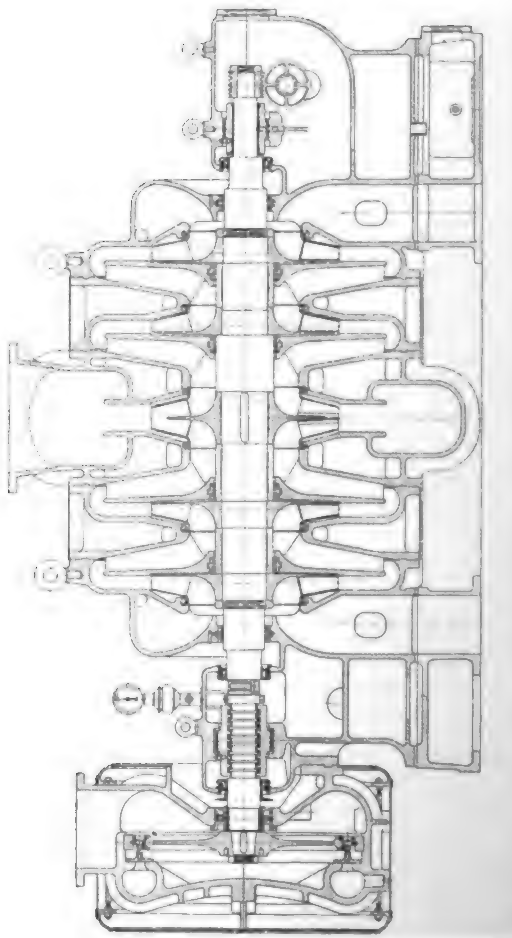


FIG. 45.—Back-pressure Turbine Driving Blower. The British Westinghouse Company, 1911.

pressure before the nozzles remains the same, are given on Fig. 42 by curve B. Curves C and D similarly connect points corresponding to ¾ maximum load and ½ maximum load.

The intercept between a point corresponding to a maximum load, and the curve E gives the ratio of the steam consumption at that

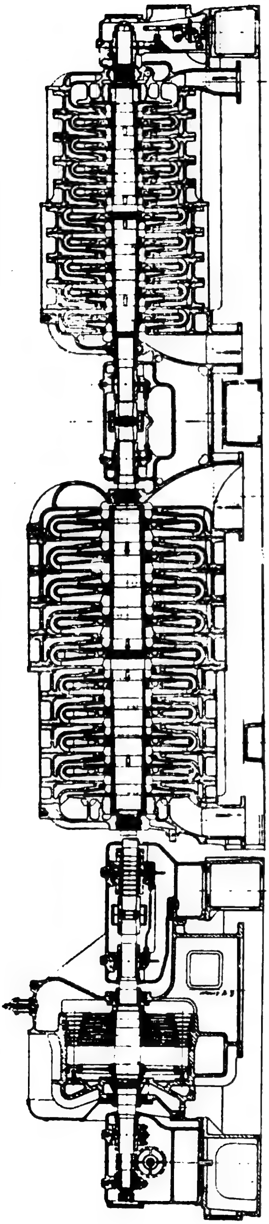


FIG. 46.—Mixed-pressure Turbine Driving Compressor. The British Westinghouse Company, 1911.

maximum load to the consumption for the full load and vacuum for which the turbine is designed.

Pressure Correction.—When the steam pressure in front of the nozzles is increased the steam consumption decreases because of the increase of available heat drop.

For high-pressure turbines the improvement of steam consumption is $1\frac{1}{2}$ per cent. for 10 per cent. increase of pressure.
For low-pressure turbines the improvement of steam consumption is 4 per cent. for 10 per cent. increase of pressure.

If, however, the turbine is working on constant load and the pressure before the governor valve is increased, the pressure in front of the nozzles remains practically constant, and the only advantage gained is that due to the increased superheat resulting from the additional throttling.

In this case the corrections for full or partial loads will be the same for high-pressure and low-pressure turbines—namely, 0·5 per cent. improvement of steam consumption for every 10 per cent. increase of pressure.

X. Development of Rotary Machines driven by Steam Turbines.

The most economical speed for small low-lift pumps and high-lift pumps is too high for reciprocating engines, and it was therefore necessary to drive these either by belt, gearing, or by means of electric motors. The advent of the steam turbine, however, made direct coupling possible, but it necessitated the further development in these pumps so that the speed might be sufficiently high to enable a reasonably efficient turbine to be built at a competitive price.

The advantages of steam-driven

pumps are often of great importance in the case of pumps used for condensing plants. A view of such a group for use with a surface condenser is given in Fig. 43, which shows a turbine on an overhung shaft driving a centrifugal pump with two double-flow impellers of the helico-centrifugal type, a rotary air pump of the Le Blanc type, and an extraction pump consisting of one double-flow impeller.

This set, which is running at 2,500 revs. per minute, is used in conjunction with a 3,000-k.w. mixed-pressure turbine for a full-load steam quantity of 80,000 lbs. per hour.

A section of a horizontal turbine driving a boiler feed pump running at 4,000 revs. per minute is shown in Fig. 44.

The influence of the steam turbine towards the development of rotary blowers, and particularly of compressors, has been of still greater importance.

Fig. 45 shows a section of a double-flow blower consisting of six wheels, driven by a back-pressure turbine, which latter consists of a single velocity wheel mounted on the end of the blower shaft. The capacity of this blower is 25,000 cub. ft. of free air per minute against a pressure of 6½ to 8 lbs. per square inch, which is the average capacity for blowers in this country. The power required to drive it is about 1,000 B.H.P., at 3,000 revs. per minute.

Whereas blowers may be arranged to be driven by motors, compressors must generally be driven by turbines as the high speeds required (4,000 revs. per minute at 1,500 B.H.P., or 5,000 revs. per minute at 1,000 B.H.P., and 6,000 revs. per minute at 600 B.H.P.) can only satisfactorily be obtained by steam turbines. The economy of turbo-compressors is very high, more particularly if low-pressure steam is available for driving the turbine. Fig. 46 shows a mixed-pressure turbine of 1,500 B.H.P. at 4,000 revs. per minute, driving a compressor for an air quantity of 7,500 cub. ft. per minute against 80 lbs. per square inch pressure. The compressor consists of twenty stages arranged in two casings.

The thanks of the author are due to the British Westinghouse Company for the preparation of a great number of the blocks required for this paper, also to Mr. M. Helfenstein for the completion and re-calculation of the test results, to Mr. H. L. Guy for the calculation of the diagrams, and to Mr. C. S. Richards, for his very valuable advice with regard to the wording of this paper.

Discussion.

Mr. Stoney. Mr. Gerald Stoney: The remarks which the author makes as to the necessity of dealing with high superheat and the prevention of trouble due to this high superheat—from differences of expansion, and also on account of the growth of cast iron—apply both to the pure Rateau and to the Parsons' turbines. The trouble due to the growth of cast iron is well known among the makers of gas engines, etc., and was investigated by Professors Rugan and Carpenter in 1909.* About

* *Journal of the Iron and Steel Institute*, vol. 80, p. 29, 1909.

Mr. Stoney.

the same time Messrs. C. A. Parsons & Co. met with the same trouble in steam turbines, and investigated it in conjunction with Mr. J. E. Stead, and although it was well known such growth took place at temperatures of 600–700° C., it came as a great surprise to find that this took place also in the presence of steam at such low temperatures as 270–300° C., or the temperature of ordinary superheated steam. There are two ways to get over this trouble. One is to use an impulse-wheel in which, by the approximate adiabatic expansion of the steam, the temperature is reduced below a point where such growth of cast iron is liable to take place. The other is to use material which will not distort permanently with superheated steam —a steel casting is such a material—and in all recent turbines of the pure Parsons type in which there is high superheat the centre portion of the casing is made of a steel casting; this has proved able to get completely over the trouble due to superheated steam. Although we use in our pure Parsons turbines a steel centre, I may say we alternatively use a Curtis wheel followed by the ordinary Parsons blading. I should expect the differences of expansion in a pure Rateau turbine due to superheat would be even greater than in a pure Parsons machine. As to whether it is best to deal with superheated steam by a steel centre in a pure Parsons turbine, or by an impulse-wheel in the disc-and-drum type, this is chiefly a matter of choice. At present the impulse-wheel is fashionable—there are fashions in turbines as well as in everything else in the world—and makers of turbines have to go with the fashion and provide their customers with an impulse-wheel—but I may say in no case have we got a better consumption nor have the costs of manufacture been reduced by the use of an impulse-wheel. If we turn to Fig. 10 in the author's paper we see that the maximum efficiency of a single row of blades is about 80 per cent., and this figure applies equally to the Rateau and to the Parsons turbine. The maximum efficiency under the best conditions of a two-row Curtis wheel is 67 per cent., but we may say that we have found that under the conditions under which it has to work at the high-pressure end of a turbine the efficiency is as low as 42 to 45 per cent. on account of the small arc of impingement and the high skin friction of the disc running in steam at considerable pressure. It wants very short Parsons blades with very big clearances to get as low an efficiency as this, and the high-pressure part of the pure Parsons turbine is practically always superior to this figure, and therefore it is possible to get the consumption of the pure Parsons turbine as a whole better than that of the disc-and-drum type. With regard to the cost of manufacture, we have found that there is little to choose between the two types. The disc-and-drum is working under the most favourable conditions in moderate sizes running at high speed, say 750 to 1,500-k.w. plants at 3,000 revs. per minute; but when we come to slow speed the result becomes much worse. For instance, a 1,000-k.w. at 1,500 revs. per minute as a disc-and-drum is decidedly worse than a pure Parsons. In comparing different sizes it will have to be remembered that, as

Mr. Stoney. the author states, the output of turbines is approximately inversely as the square of the revolutions. The disc-and-drum is useful also in cases where a turbine has to be put into a restricted space, as sometimes happens in connection with the extensions of old stations, but in cases where a new station is being laid out this does not come in, as the area taken by the turbines is a very small part of the whole station, which includes boiler house, switchboard, etc. The disc-and-drum is also useful in small sizes—say 500 k.w. at 3,000 revs. per minute—where there is a very high boiler pressure of 180 to 250 lbs., in which case the pure Parsons turbine cannot take the full benefit of the boiler pressure.

Another point to be considered is the cutting of the impulse blades due to the high velocity of the steam. This is not so much the case if there is always high superheat, but with moderate superheat, or with saturated steam, it is very rapid. We have tested Curtis blading in a jet of saturated steam issuing at 150 lbs. and exhausting into the atmosphere, and no material, even the hardest steel, will stand this jet without being cut for a space of only 45 hours. Many of those present, no doubt, will have seen the illustrations that we have shown of a file that has been cut by such a jet of steam. Several warships have been fitted with Curtis wheels, and in them it has been found that the cutting of blades has been very rapid. One battleship showed such bad cutting of the blades, even after it had only completed its trials, that it was estimated that the blades would require renewing by the time the vessel reached the other side of the world. I am much interested in what the author says about carbon glands not being as reliable as labyrinth. Of course I have had no experience dealing with such high pressure on glands as there is in the pure Rateau turbine, but we have never had any trouble with our labyrinth glands with pressures up to 20 or 30 lbs. above atmospheric. The author says that for large outputs the Curtis and Rateau turbines are the better because the disc-and-drum type would have to be made double-ended in the low-pressure part, which would considerably increase the cost of the turbine. This is a statement, I am afraid, that I cannot agree to. For larger sizes we have adopted the tandem formation of turbine, which was first introduced for the 1,000-k.w. turbines which we supplied to Elberfeld, in Germany, and recently we have made eight 6,000-k.w. turbines for the Lot's Road power station of the Underground Railway Company, of London, to replace other turbines which were there, and may say they have brought down the coal bill from somewhere about 3¼ lbs. per kilowatt to 2¼, and that practically the cost of the change has been already saved. These turbines are of the pure Parsons type, and thus the efficiency that was obtained, even in the high-pressure part, was higher than could be obtained with a Curtis wheel. Dividing the turbine into two parts enables the spindles to be kept very short; in fact, at Lot's Road the length between the shoulders of both the high-pressure and low-pressure spindles does not exceed 7 ft. Also in the small high-pressure cylinder,

the whole of the high temperature is dealt with, and thus distortion is minimised; besides this a steel centre can be used. Good blade-height is obtained, and therefore the leakage is small. In larger sizes there is no difficulty at all about double-ending, and we have not found that it appreciably increases the cost. We do not think it advisable to go above moderate speeds for the low-pressure blades on account of the large terminal loss, as pointed out by Mr. Baumann, but in certain cases, where it was desired to go to higher speeds, we have adopted a disc form of spindle, which we have used for blowers for many years, and with which there is no difficulty in going to the same speeds as with the wheels of a Rateau turbine. For large sizes, such a combination of a small Parsons high-pressure turbine in tandem with a low-pressure, single- or double-ended, exceeds the efficiency of any combination with a Curtis wheel. I may further say that in every case during the last year we have got our guaranteed consumptions on test, except in one case of a disc-and-drum machine. Mr. Stoney.

The author further says that he does not consider caulked-in blades to be safe for high stresses. This, again, I must beg to differ from, as we have never yet had a case of blades coming out due to centrifugal force, except in one or two cases which were clearly traced to bad workmanship. In tests made on our blades it is quite common for the blade to break off rather than pull out. From what I have before said, it will be seen that the maximum output of the Parsons turbine is the same as that obtainable from the disc turbine, and I may say that Fig. 23, which is a most interesting way of putting the question, practically agrees with our figures, and is equally applicable either to the drum or to the disc type of turbine. With reference to what the author says about critical speeds, I think the way he has put it is clearer than I have ever seen it before, and I am much interested in the statement that it has been found necessary to keep the Rateau turbine below the first critical speed. I know that in the past there has been great trouble with the diaphragms of the Rateau turbine where clearances have to be very fine. It is necessary in any type of compound turbine to have fine clearances at some point between one stage and the next. In the Rateau and Curtis turbines this is in the glands of the diaphragms, and in the Parsons it is between the blades and the casing or rotor. Each party, of course, claims that their way is the best, but I think, looking at it broadly, there is not much to choose between the two. What the author says about there being liability to trouble with three-bearing turbines and alternators where they are rigidly coupled together is very interesting in view of the great trouble there has been in some large turbines in the North of England that are made in this way. With reference to low-pressure turbines, the author says that the great importance of these was pointed out by Professor Rateau, who first installed them in 1903. I would beg to refer him to Sir Charles Parsons' patent in 1894, which had been, until it expired, the master patent, and I may say that the torpedo-boat destroyer *Velox* was built in 1902, in which for cruising purposes there

Mr. Stoney. were reciprocating engines exhausting into the turbines. The table of consumptions which the author gives is most interesting and complete, and I am glad to see that the list is headed with 68·4 per cent. efficiency in the Richardsons-Westgarth Parsons turbine at Dunston, which is of the pure Parsons tandem type as described above. The tables of corrections for superheat and vacuum are very interesting, and practically agree with our figures, but I cannot agree with the author where he states that the Parsons turbine cannot utilise very high superheat, the figures he gives being exactly in accordance with our practice. Also he says that the drum turbine cannot be designed for as high a vacuum as the disc turbine. I have already shown the fallacy of this statement, and may say that the overall efficiency of a properly designed Parsons turbine is as good for 29 in. as 27 in. vacuum, and this is amplified in the tests of the above Richardsons-Westgarth Parsons turbine, which had a vacuum of 29·1 in, barometer 30 in., or only 0·45 lb. absolute. The author does not touch on the most recent adaptation of the turbine to drive slow-speed machinery by the use of helical gearing. The Westinghouse Company in America have already utilised it for driving continuous-current dynamos, and we are doing the same. We have working also a rolling mill running at 70 revs. per minute, driven by a 750-H.P. turbine at 2,000 revs. per minute, and in marine-turbine work gearing is being extensively adopted. The experimental cargo boat *Vespasian* is giving 15 to 18 per cent. better consumption than could be obtained with reciprocating engines, and two destroyers and two cross-channel boats are also being fitted with gear turbines.

Mr. Samuelson. Mr. F. SAMUELSON: On looking through the paper I find no mention is made of a Curtis turbine being built in this country, although no less than 138 machines have been shipped from Rugby ranging in sizes from 200 to 5,000 k.w. In Fig. 10 the author gives curves of calculated efficiencies of Rateau and Curtis wheels, *i.e.*, wheels with one, two, and three rows of buckets. If the efficiencies there given corresponded with actual efficiencies as now fully determined by numerous tests, the single-wheel construction would be so far superior that any other type would not exist. That this is not the case is clear from the table given in paragraph 8, where a large number of machines are compared, and taking the 3,000-k.w. 1,500 revs. per minute turbine for comparison we find that the B.T.H. Curtis turbine shows the highest efficiency. The author gives some interesting particulars about the stresses in turbine wheels of different designs, and also gives formulæ for calculating these stresses. In Fig. 22 curves are given of the tangential and radial stresses in turbine wheels, but no mention is made of a very important factor, viz., the expansion of the wheel-bore due to these stresses, and the formulæ provided by the author do not enable us to get at these expansions. Of the examples given by the author under Fig. 22, I calculate that wheel "A" would expand in the bore 0·0054 in., while wheel "C" would expand 0·0043 in. in diameter. This expansion in the bore must be studied carefully, or trouble will be

experienced from loose wheels. Under paragraph 6 on governing of steam turbines, the author states that the nozzle governing complicates the governing gear to an extent not justified by the increased efficiency gained thereby. I would point out that all Curtis turbines built in Rugby are nozzle governed, and that the governing gear is well known for its simplicity and its certainty of action. The author states that by means of nozzle governing an improved efficiency of 2 per cent. is obtained at ¾ load, and 4 to 5 per cent. at ½ load. These improvements are surely worth having, as 4 to 5 per cent. represents quite a big amount in the coal bill in the course of a year. Further, a machine which is perfectly automatic and does not require any manipulation from the station attendant, either from change in load or change in steam conditions, such as drop in pressure or drop in vacuum, is a valuable feature in the station, and it may be prophesied that all turbine builders will adopt this method as soon as circumstances permit. The value of mixed-pressure machines is daily getting more understood and appreciated, as pointed out by the author in stating that nearly 40 per cent. of the orders executed by the British Westinghouse Company are for mixed-pressure turbines. About the same percentage applies to the turbines built by the British Thomson-Houston Company at Rugby. Most of these mixed-pressure machines are operated in conjunction with some type of heat accumulator, and in connection with these machines I wish to draw attention to a very important feature, viz., the utilisation of the exhaust steam available under all conditions. The low-pressure end of the turbine being connected to an accumulator, the maximum pressure is fixed at which the accumulator can regenerate the steam. Taking the case of a 1,000-k.w. mixed-pressure turbine such as is illustrated in the paper in Fig. 30, and assuming that the accumulator will generate at a maximum pressure of 16 lbs. absolute and that the machine requires 33 lbs. of steam per kilowatt-hour, the maximum total amount of steam passing through the low-pressure part of the turbine would be 33,000 lbs. of steam per hour. In other words, the nozzles in front of the turbine are designed to deal with full load at a maximum pressure of 16 lbs. If an overload is demanded of the machine while 33,000 lbs. of exhaust steam is available, and we assume this overload to be 25 per cent., it will be impossible for the steam coming from the high-pressure portion of the turbine to find its way through the low-pressure wheels, and at the same time admit the full quantity of 33,000 lbs. of low-pressure steam. It may be further assumed that the steam consumption on the high-pressure part of the turbine working between, say, 165 lbs. and 16 lbs. absolute is about 40 lbs. per kilowatt-hour. The low-pressure nozzles are already dealing with the maximum steam, and any further steam coming from the high-pressure wheel must find its way out of the system through the relief valve in the low-pressure pipe system, or, in other words, the accumulator will not be able to supply its available quantity of steam. 250 k.w., the overload, at 40 lbs. per kilowatt, represents 10,000 lbs. of steam, so that instead of being able to discharge at the rate of 33,000 lbs. per hour, the accumulator can Mr. Samuelson.

Mr. Samuelson.

only discharge 23,000 lbs. per hour, the available surplus of 10,000 lbs. being blown to atmosphere from the relief valve. To overcome this difficulty, the British Thomson-Houston Company have designed a mixed-pressure turbine wherein this objectionable feature is absent.

From Fig. A it is seen that entirely separate nozzle openings are provided for the low-pressure steam, capable of giving the full output of the machine at the desired pressure. If the machine is called upon for an overload, high-pressure steam passes through the first wheel, then through separate nozzles in front of the second wheel, and mixes with the low-pressure steam in front of the third-stage nozzles. By this

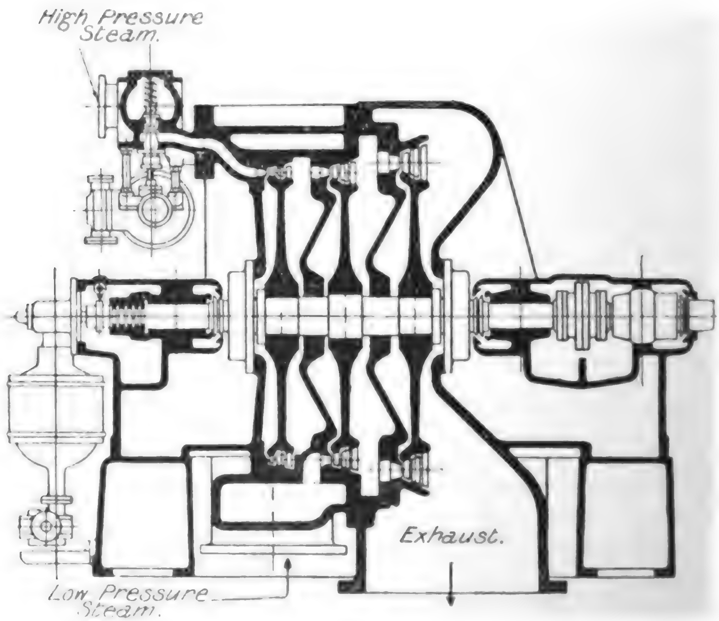


FIG. A.

arrangement there will be no interference with the low-pressure steam, the turbine continuing to do full load on low-pressure steam as long as this quantity is available, at the same time doing the 25 per cent. to 50 per cent. overload with the assistance of the high-pressure steam without interference with the low-pressure supply. In the mixed-pressure turbine, as shown in Fig. 30 in the paper, it will be obvious that while the machine is running on pure exhaust steam the two high-pressure wheels will be running idle in steam, of a density equal to that in front of the low-pressure nozzles, *i.e.*, about 16 lbs. absolute. Referring to the diagram of the B.T.H. mixed-pressure machine, the author pointed out that while the machine is operating on pure low-

pressure steam the first stage wheel will run idle in steam of density equal to that of the density in the second stage, *i.e.*, about 5 lbs. absolute. This reduced steam pressure in the first stage cuts down the losses from disc friction and windage to ⅓ as compared with steam at 16 lbs. absolute. A further advantage is that when running as a pure high-pressure machine the nozzle areas and pressures can be maintained correct for both first and second wheels with correspondingly good efficiency, while in the design shown on Fig. 30 the whole of the low-pressure end will have too large nozzle areas giving incorrect velocities and poorer efficiency. In paragraph 8 the author states that the best efficiency of mixed-pressure turbines running on low-pressure steam has been obtained by the British Westinghouse Company, the efficiency being 69·8 per cent. Details of this and other mixed and low-pressure test results are given in Table VII., and it will be noticed that this efficiency of 69·8 per cent. has been obtained with the assistance of 128° F. superheat. In paragraph 9 the author deals with corrections for superheat, vacuum, and pressure, and there makes a statement that 4·25 per cent. better efficiency is obtained with 100° F. superheat than with dry saturated steam on low-pressure turbines. Referring to Table VII., tests are given of a B.T.H. 1,250-k.w. mixed-pressure turbine; the efficiency on low-pressure steam is given of 68·2 per cent. with 24° F. superheat. Assuming that this B.T.H. turbine had been running with 128° F. superheat, and applying the author's corrections, the efficiency would increase from 68·2 per cent. to 71 per cent. Mr. Samuelson.

Mr. R. J. KAULA: Perhaps the most important section of the paper deals with the relative merits of the disc and disc-and-drum type turbines, and as the largest makers of turbines of the latter type in this country I think our designs might have been referred to. I quite agree with the author that for small and moderate-size turbines the disc-and-drum type is the best design—assuming the drum to be bladed on the reaction principle; but I would like to go one further and say that the same relation holds for large outputs. The author's arguments against this statement are based on two main facts: viz., that the output for a given speed is limited by the heavy losses, and consequently by the diameter of the disc or drum at the low-pressure end; and secondly, that a drum cannot be run at so high a peripheral speed as a disc. As regards the first assumption, I think some allowance must be made for skin friction losses, and as these vary approximately as the 5th power of the diameter on the disc, and about as the 4th power on a drum, we have an advantage here in favour of the drum construction. The author asserts that a disc without a hole in the centre can be stressed higher than one containing a hole, and I consider that a solid drum should be treated as the former. The question of homogeneity can be dealt with otherwise than by allowing only half the stresses, as suggested. Mr. Stoney has already described another useful method of construction. Consequently, we are able to work to at least equally low exhaust losses with a disc-and-drum design as with discs, with the further advantage Mr. Kaula.

Mr. Kaula. of lower skin-friction losses. The well-known Willans method of blading lends itself admirably to high-speed working, and as a fact we find that we are generally able to keep one ahead of our friends the generator makers on the output speed curve without sacrificing economy and without adopting double-flow designs. Turning to the question of efficiency, I am very pleased to see the author adopts the only correct method of comparison by making proper efficiency corrections for varying superheats and vacua. We hear far too much about extraordinary efficiencies and steam consumptions without any reference being made to the steam conditions. The total efficiency, or overall efficiency ratio, is the figure that concerns the user. Table V. is of exceptional interest to me, as this gives the efficiencies which have been obtained on Curtis-Rateau turbines, presumably under favourable conditions. This shows a maximum efficiency of 67·9 per cent. for this design. I take it, therefore, that this is as good a figure as may be expected from this type of turbine unless the output is increased or unless the steam conditions are more favourable. My firm and I have refrained from publishing results obtained on the disc-and-drum type turbines, and whilst I have no intention of departing from this practice, I may refer to our first experience with this design. This consisted of converting an existing turbine of the plain Parsons type to the disc-and-drum construction, and I think that it will be admitted that the result of an alteration of this description can hardly be expected to show the new design to best advantage. Yet even so we were able to get within 2 or 3 per cent. of the maximum efficiency shown for a Curtis-Rateau turbine, viz., 67·9 per cent. We have naturally been able to improve this design to a considerable extent since that date.

With very few exceptions, test results do not take account of the amount of water contained in the air discharged from the condenser. The amount of water in question is approximately equal to that contained in saturated air, or at the temperature and pressure at which the air is separated from the main body of water condensation. With a wet air pump, such as the ordinary Edwards type, the pressure is that of the atmosphere. With a dry air pump, such as all rotary pumps now on the market, the pressure in question is that at the air pump inlet, *i.e.*, the vacuum pressure; assuming, for instance, a temperature of 80° in both cases, and atmospheric pressure of 14·7 lbs. absolute, and a pressure of 1 lb. absolute as the inlet temperature to the condenser, then a ratio of the quantities of water per unit of air is 33 to 1. It follows that whilst the quantity of water then dealt with is negligible in the case of a wet air pump, it may be appreciable in the case of a rotary air pump. Mr. Stoney has commented unfavourably on the disc-and-drum design, and considers that the call for this design is merely a fashion. Like all other fashions, it is a matter which one has to get used to, or, in other words, one has to buy one's experience on the particular design. We have now managed to get used to this fashion and to like it in so far as we find that we are able to get a better

efficiency with the disc-and-drum type than we can obtain on a plain Parsons design, and moreover, the greater reliability is decidedly marked. Mr. Kaula.

Mr. S. J. WATSON: In considering the paper from a turbine-user's point of view, I think we have to look first of all at the results, and although I have very carefully considered the tables placed between pages 826 and 827, I find it almost impossible to say which of the different makes of turbines is likely to give the best results. As far as I am able to judge, there is practically no difference between the types either in the steam consumptions or in the efficiencies; the final choice, therefore, to a large extent, depends on the reliability of the machines under working conditions. In the past I must admit—as the point has been raised by many other speakers—it has not always been possible to get the exact conditions under which test-figures have been obtained, and the information given by the author concerning the adjustments which must be made when the vacuum or the superheat vary from a certain standard, is of considerable value, and will be found most useful to many of us. One of the most important points in the paper is, I think, that dealing with critical speeds. If, as the author says, our critical speed is below our running speed, we have to run through the critical speed in order to get the machine running at the speed for which it is built. I have a case in mind where the critical speed occurs at about two-thirds the working speed and it occasionally happens when running up that vibration occurs and the plant has to be slowed down and then restarted. Sometimes this course has to be adopted two or three times. The amount of vibration set up at the critical speed appears to depend to a large extent on the rate of acceleration through which this speed is passed. Table I., on page 796, clearly sets out the difference in the steam volume with a vacuum of 27 to 29 in. The volume at 28½ in. is double that of 27 in., and illustrates very clearly why it is that such good results cannot be obtained with a high vacuum with reciprocating engines as with turbines. The low-pressure cylinders of a reciprocating engine would have to be at least doubled in size for 28½ in. as compared with 27 in. in order to get the results which are readily obtained from the design of all makers of steam turbines where ample low-pressure areas can so easily be constructed. There is another point I should like to refer to in connection with the use of velocity wheels. The author appears to deprecate the cutting-out of nozzles at light loads. This is a question of considerable importance to undertakings who have to run their machinery during some portion of the day at loads very much under full load. Many of those present may remember that in the past there have been many discussions on the difference between the throttle governing and automatic expansion governing in connection with reciprocating engines, and I take it that this question of nozzle governing or throttle governing is of a similar character. If the steam consumption can be reduced at light load by 4 or 5 per cent. by means of either hand-operated or governor-controlled nozzles, the question becomes of no Mr. Watson.

Mr. Watson. little importance, and cannot well be overlooked. At the bottom of page 781 the author states that the "efficiencies of velocity wheels with more than three rows are still worse, and they are therefore not used except for marine turbines." I think marine engineers are as keen on high efficiencies as we are, and I am therefore unable to understand this expression.

Dr. Rosenberg. Dr. E. ROSENBERG: One striking feature of this paper is its absolute fairness, and I do not know whether that has been recognised sufficiently in the discussion so far. This fairness applies to the relative merits of the different systems as well as to the curves for correction of steam consumption under different conditions, and to the comparison of the best results obtained. When a man gives, as the author has done in the table on page 826, the best overall efficiency obtained with turbines and generators as 68·4, and the best efficiency obtained on machines of his own designs 67·9, that speaks volumes, because whoever knows how frequently figures for publication are juggled about will recognise how easily the author could have made "corrections" amounting to a little bit above ½ per cent., and so headed the list. But he was quite satisfied with absolutely fair figures to state that his record is ½ per cent. under the best record. As the figures given in this table include the generator efficiency, I would mention that the electric machine of the No. 27 set is a 2-pole machine for 25 cycles, and that the efficiency of such a generator is slightly lower than that of a 4-pole machine (No. 28 set). Whether the turbines designed by the author have the very best overall efficiency or stand ½ per cent. back, anyhow, the author has the remarkable record that not one turbine designed by him exceeded the guarantees given, which proves that he is not only a very successful but also a very conscientious designer. On page 817 it is mentioned that with exhaust turbines, for starting and paralleling, generally high-pressure steam is required, which is either regulated by hand or by a mechanical governor. I would just mention an interesting installation where the necessity of high-pressure starting has been avoided by a novel electrical arrangement. The Birmingham Corporation, when they considered installing exhaust turbo-generators to increase the output of their Summer Lane station, intended installing induction generators with squirrel-cage rotors which should work in parallel with the engine-driven alternators, being brought up in speed together with the alternators, no high-tension switch being provided for the turbo-generators. Going closer into this very ingenious scheme, I found that the wattless current of the additional load, and also the magnetising current of the induction generators, would overload the engine-driven generators with wattless current to such an extent that this installation would have been only possible on a few of the sets if all the other existing engine-type generators could be used to help out with wattless current, but that it could not be used as a general proposition. We obtained, however, the desired result by supplying synchronous turbo-generators with exciters direct-coupled to them and connecting the exciter field in parallel to the field of the main generator. The rotor of the turbo-

generator is also fitted with a damper. Before starting, the field of the main generator is excited. In running up to speed the turbo-rotor can never have a speed much different from the speed corresponding to that of the main generator, because the damper acts as a squirrel-cage, and if the exhaust steam gave insufficient power in the turbine, the damper would cause the turbo-generator to run as an induction motor, or if the power of the exhaust steam in the turbine is more than that required for the no-load losses (and that, of course, will be the rule), the damper will cause the machine to act as an induction generator, giving, at slight over-synchronous speed, some power back into the main generator, so helping to drive it. But already at comparatively low speed the direct-coupled exciter gives sufficient E.M.F. to pull the turbo-generator into exact synchronism, and it will remain in synchronism. This arrangement—which has been patented—not only simplifies the starting so far as the steam end is concerned, but also simplifies considerably the switchgear, as no switches are provided on the high-tension side. So far as the exciter field of the turbo-generator is concerned, there is only an adjusting rheostat, which can be set once for all. It was necessary in this case to use a direct-coupled exciter because the exciting voltage of the main generators (440 volts) is not suitable for a turbo-generator. All the main generators of the station are supplied from common direct-current exciter mains, the exciter generators being regulated by means of a Tirrell regulator. These direct-current generators were practically loaded up to the utmost of their capacity. Two of these exhaust turbo-generators (Bellis and Morcom turbines with Westinghouse generators) are in service, and three others are being installed. Dr. Rosenberg.

Mr. P. A. SANDERS: I would suggest that as the previous speakers represent a large portion of our turbine talent in this country, and since they have all so far stated that the correction figures given by the author agree almost entirely with their own, his figures could be taken as a standard to work upon, when firms publish their results of tests, so that at a glance the figures could be compared with previous results of other makes. Such an arrangement would be extremely useful to buyers. I do not altogether agree with what the author says on page 805 concerning disc and ordinary drum construction. My experience is that the latter gives very much more trouble in balancing when "out" than the former, as in the latter the static balance hardly ever agrees with the running balance, due to the fact that the balancing arrangements of the drum type are confined to the two ends of the same, whereas the out-of-balance mass may be located far away from the ends, and then couples and strains are produced in the drum; in the disc type, on the other hand, each one can be separately balanced, thereby ensuring that the out-of-balance mass is compensated for in its own plane of rotation. It is much harder to detect "inhomogeneity" in drums than in discs, and there is much more chance of its existence, and any unsoundness or inaccurate machining has much more effect upon the balance with drums than discs. I have never found a case Mr. Sanders

Mr. Sanders. where an accurately statically balanced set of discs had to be rebalanced for running. These remarks I have not found altogether true for vertical shafts. On page 807 the author mentions the critical speed of shafts. I think an equally important critical speed is that of the discs, because of the effect the steam may have upon them when running, due to the position of the openings in the preceding nozzles or diaphragm. This critical speed can be easily found statically by means of a vibration tachometer. Mr. Stoney has mentioned the splendid results of the turbines installed by his firm at Chelsea. I agree with him the results are splendid. But if a glance is cast at the table the author has given us, it will be seen that there are many firms to-day who are building turbines equalling the Chelsea ones. I think it would be surprising indeed, with all the intellect and experience lately brought to bear upon the turbine field, if the original figures given for Chelsea some ten years ago could not now be greatly improved upon. And I venture to say that the present position of turbine efficiency is largely due to the high state of condenser manufacture, particularly with regard to Chelsea. I think that the greatest credit is due to the original manufacturers of the Chelsea machines, because they proved absolutely that these enormous units could be manufactured satisfactorily as long ago as nine years. Reference has been made to cutting of blades by steam velocity in turbines of the compounded pure impulse type. I have just lately been carrying out a very careful investigation on this, and have had very many turbines of this type opened up in the last few months, turbines of all sizes and running under all conditions of service. The investigation shows that after very many months of service not one of them has manifested any distressing signs of cutting due to this cause. The author has mentioned that the General Electric Company of America and their several associate companies have decided to do away with the vertical shafts in their turbines. I am sorry to hear this, because I know the Curtis vertical machine to be a very excellent one mechanically, which has done great service in the States and elsewhere. I believe that a large portion of the trouble which has been experienced in this country with this type of spindle is due to erection, which I think, if not perfect, is fatal to this type.

Mr. McKenzie. Mr. A. E. McKenzie: As a user of two of the largest impulse turbines in the country, I rise to say something on behalf of that particular type of turbine, because so far we have only heard the makers of the other types. There is apparently no one here to uphold the impulse type. It certainly must be admitted that the Curtis-Rateau, or the Curtis-Parsons, ought to be made cheaper than the plain impulse type. On the other hand, we have found when obtaining competitive tenders that impulse type makers in this country are quite able to hold their own with regard to price against makers of the other types mentioned. I think it is generally admitted that a slightly higher efficiency to start with can be obtained with the plain impulse type, and also that, due to the absence of blade erosion, the efficiency is

maintained longer with the impulse type than with either of the other types. I was very pleased to hear what Mr. Sanders said with regard to the machines he had inspected—that no blade erosion had taken place; such has not been my experience, I am sorry to say. With regard to the machine that we had altered—I speak of the 6,000-k.w. set at Stuart Street—from the plain drum to the combined disc-and-drum type, I am very pleased to say that it has been a complete success, and it is certainly now a reliable machine in every way. As regards the governing arrangement of our disc-and-drum turbine, I support Mr. Watson in what he said. I think control of the number of nozzles is desirable. We have a large number of reciprocating engines and turbines, and find it pays to run turbines from one week-end to another, and the reciprocating engines are kept for the peak load. Frequently the turbines are running at only half their rated output at times of light load, and the number of nozzles is regulated accordingly. I do not, perhaps, see eye to eye with Mr. Samuelson when he states that the regulation of the nozzles should be automatic. I do not think it is necessary in stations of moderate size. We have, in Manchester, to deal with fogs as bad as most people get, but there is always time to open the nozzles to deal with the rising load. I have no doubt that most of the engineers present here to-night were very glad to hear Mr. Stoney say that the stripping of reaction turbines can now be absolutely prevented. I know one station engineer on the Continent will be pleased to hear of it, for in November last he had three 5,000-k.w. sets down at one time through blade-stripping. A friend of mine actually saw them. For the blading nickel steel has been largely used in this country in late years, while on the Continent I understand bronze or brass blading is growing more in favour. Where nickel blading is used, the percentage of nickel is often as high as 25. With regard to the effect of high temperatures in the Zoelly type of turbine, such as we have at Manchester, we find it is quite able to withstand these temperatures. One set has been running now over two years with absolute satisfaction, and we have no hesitation in running with steam at a total temperature of 550° to 600° F. Most of those present will probably be interested to hear that with the last set installed at Stuart Street there is a de Laval turbine of 450 H.P. running at 7,500 revs. per minute, geared down to 750 revs. per minute for driving the circulating water pump. This is, I believe, the largest de Laval turbine that has been built in this country. It has been running satisfactorily for about two months, and I do not anticipate any trouble with it in the future. The author has given in his paper some of the most important tests that have been carried out in this country on turbo-generators, but the test results on the 6,000-k.w. Howden-Zoelly set at Stuart Street are conspicuous by their absence. I venture to say the results obtained are equal to, if not better, than most of those cited. Mr. McKenzie.

Mr. J. DRUMMOND PATON (*communicated*): In the discussion the question of blade corrosion and wear has already been raised and partly discussed, the effect being considered as mainly the result of Mr. Paton.

Mr. Paton. dynamic action. I should like to put forward the following theory as to the cause of this corrosive action. Every degree of superheat added to the steam is simply bringing it one stage nearer the temperature of dissociation; if this gas therefore be subjected to a very high velocity, and its path (for the purpose of illustration) be considered a straight line, the tendency to dissociation is increased, for the relative densities of the constituents of this steam gas—*i.e.*, oxygen and hydrogen—are as 16 to 1. If we consider the condition of an atom of gas in the line of flow, and the action assumed to take place, it can be similarised to the behaviour of a drop of composite viscous matter when travelling through space at a high velocity: the denser or heavier constituent is at the front of the particle, and the lighter at the rear. This dynamic action, tending to produce dissociation by the dragging of the lighter element, can be calculated in terms of the velocity and relative densities of the constituent elements; and for total dissociation would simply be equal to the energy given out from a known volume of dissociated gas when turned into steam or water by combustion. What I consider therefore as the cause is the action of an oxidising gas, or the impinging of the atoms of this gas under conditions which bring the denser and oxidising element into contact with the blades under more favourable conditions for scoring and wear to take place. A certain amount of wear through water impinging and gases passing over the blade surface will necessarily take place, but it is a known fact that the addition of fixed quantities of nickel, or even the substitution of gun-metal, has greatly reduced the wear on blades. These improvements have been due, I consider, in the case of steel, to the formation of a eutectic in the metal, which has offered a higher resistance to the oxidising action of the gases, or, in other words, has caused the ingredients of the alloy to pass into closer combination, leaving no vulnerable points. In the case of gun-metal the dendritic formation of the particles, and the absence of a relatively easily oxidised subject, such as carbon in steel, has reduced this case to one of physical wear as the main cause of trouble, and where metal of sufficiently high tensile strength has been used and the steam has been free from moisture, gun-metal blades work satisfactorily. The scoring of cast-iron cylinders by superheated steam is well known, and the diminution of its effect by the use of "white iron," *i.e.*, iron in which the carbon is in solution, is equally well known. The close formation of the particles in nickel steel, and the absence of free carbon, are the reasons for its successful application. The trouble originates from the dissociated gases, and by the application of metals which are suitable it can be overcome.

Mr. Adamson. Mr. D. ADAMSON (*communicated*): Referring to Section VII. of the paper, page 823, dealing with reducing turbines, I should be glad if the author would tell us the pressure and quality of the steam supplied to this turbine, and also give us some information as to the total efficiency of this class of turbine, that is to say, the ratio between the mechanical equivalent of heat drop according to adiabatic expansion and the actual output on generator, as referred to on page 827 of the paper.

Mr. Livingstone.

Mr. R. LIVINGSTONE (*communicated*): The author's remarks on the tendency of present-day design are very much to the point, and when my firm, Messrs. Dick, Kerr & Co., took up the manufacture of steam turbines, they fully realised that the turbine of the future would be one in which large clearances and low temperatures were obtained in the cylinder, provided these points were not off-set by poor steam consumptions. The type adopted was an impulse turbine, with a high-velocity first wheel, and the efficiency of this type of turbine is quite comparable with any other make. On page 782 the author gives a curve of efficiencies of Rateau-Curtis wheels, and in the text it is stated that this represents a fair average of test results actually being obtained in the low-pressure parts of modern Rateau turbines. It would have given much greater weight to the curves if the author had given his method of separating out the different losses so as to arrive at the efficiencies there given. From the value of the efficiencies it appears that the efficiency here given is the blade efficiency at the periphery of the wheel, and is no doubt obtained from the overall efficiency of turbine by deducting the gland and bearing losses, so that their accuracy depends on the correctness of the values taken for these losses. Although not stated, it is evident that the curves represent the efficiency of the wheels when the outlet velocity of the steam is again used. Although I agree that the Curtis-Rateau is a better type of turbine for large outputs than the Curtis-Parsons type, yet I consider that the author in his calculations has accentuated the difference too much. First of all, in comparing the stresses in discs with the stresses in rings he has considered only simple discs and simple rings. In actual practice the periphery of a disc is usually cut away to some extent to form fastenings for the blades, and this very considerably alters the stress at the periphery of the wheel, and in some cases these stresses become of greater importance than the stresses in a simple disc, so that in comparing the permissible peripheral velocities we must always take account of the detailed stresses in the disc and in the ring. Again, in comparing the permissible length of blades only the effect of centrifugal force has been taken into account, but in the longer blades which can be used in disc turbines, owing to the larger diameter of disc, the bending stress due to the force of the steam becomes appreciable, and this also tends to modify the comparison of output between the disc and the drum turbine. The influence of these factors is not great, but it is only fair to the drum type of turbine to take them into consideration. It is quite possible that the makers of the drum type of turbine will go further than this, and say they can make a turbine of equal output to a disc type of turbine at the same speed. In considering the critical speed of turbine rotors, the author gives a good deal of the credit for the investigations of the phenomenon of critical speed to Professor Stodola, but Professor Reynolds deserves the credit for the theoretical investigations of this important subject, and a very thorough investigation of the critical speed of shafts with different methods of loading was made by Professor Dunkerley in

Mr. Livingstone.

1893.* Corrections required to the efficiency of a turbine for pressure, temperature, and vacuum are well known to designers, and the author has put these in such a clear way that undoubtedly they will appeal to engineers generally and render comparisons of the steam consumptions of the different types of turbines more real than they have been. Very often when a low steam consumption is obtained on test, the turbine maker claims all the credit, whereas the whole of the credit is often due to the makers of the boilers and condensers. Table III. is mentioned on page 838, which I presume should be Fig. 42, and in Table IV., Test No. 26, the pressure in A and B is greater after the governor valve than it is before the governor valve, the thermal drop in A is greater before the governor valve than after the governor valve, and the thermal drop in B is greater after the governor valve than before the governor valve. This requires some explanation.

Mr. Maclean.

Mr. R. J. MACLEAN (*communicated*): When reading this paper one is struck by the great number of alterations in design which have taken place in quite a short number of years, and which show a distinct tendency towards machines of the impulse type, as it will be noticed that quite a few makers of reaction turbines are now building impulse turbines or making a compromise by substituting the initial stages of their machines for impulse-wheels. A great number of these changes must of necessity be in the experimental stage. These the buyer will rightly fight shy of if known. Changes of design are brought about mainly by three circumstances: First, and most important, by faults discovered in practical running; secondly, by commercial competition requiring cheaper production; and thirdly, by individual enterprise on the part of the designer. Those coming under the first are by far the most important and are brought about by absolute compulsion. From the time the machine starts up on the test-bed defects of a very varied character are encountered, which are unforeseen when passing through the designer's hands or the drawing office. Every endeavour is made to locate and rectify these and other troubles which may occur before leaving the shops, but unfortunately it is not always possible to do this, and many of these defects will not show for some considerable time after. This applies to a much greater extent when changes of design are taking place, and those who have had dealings with earlier turbines will thoroughly appreciate this. With reference to the second heading, it must always occur that commeroial competition will change designs, and even those which are mechanically efficient must succumb when the question of reducing production costs is encountered. Thirdly, we have the changes brought about by the designer's own initiative, which may depend on the above conditions and the latitude given him for experimental work. As a proof of my contention that the change is gradually towards pure impulse as in the Zoelly, which still maintains the original design and yet gives results equal to any other, I would refer members to the test figures of the 6,000-k.w. high-pressure turbine at the Manchester Corporation electricity works. This machine will

* *Proceedings of the Royal Society*, vol. 54, p. 365, 1893.

give an output of 8,000 k.w. quite comfortably and 10,000 k.w. on the by-pass valve. Since these test figures were taken a further 7,500-k.w. high-pressure turbine set has been installed, and also a 4,000-k.w. pure exhaust turbine has been ordered to utilise the exhaust steam from the existing sets, this latter being the largest of its kind in the country. Mr. Maclean.

Mr. V. O. Davis (*communicated*): It may be of interest to include here a photograph of the 20,000-k.w. A.E.G. turbo-alternator mentioned on page 807 of the author's paper. Fig. B shows the latest design with horizontally divided front cover and diaphragms. The speed is 1,000 revs. per minute. In addition to this machine the A.E.G. have a large number of machines of 5,000 to 5,600-k.v.a. output at 3,000 revs. per minute under construction. It is interesting to note that the latter sets disprove the statement made on page 821 that the limit to the maximum output depends more on the generator than on the turbine in the case of pure high-pressure sets. In this case the turbine is, as far as present knowledge goes, nearly up against its limit, though the steam conditions prevailing on the Continent are almost invariably considerably more favourable than those for which Fig. 23 has been drawn. The author's formula connecting critical speed and deflection of shaft will, I am sure, be welcomed by many designers. The arrangement of the Rateau governor gear for mixed-pressure turbines shown is certainly very neat and well placed to avoid taking up unnecessary space. The emergency valve on the low-pressure side is not shown on the illustration; I assume that this valve and the main low-pressure stop-valve are placed externally. The gasometer type of exhaust steam accumulator is finding a good deal of favour on the Continent. The governing gear shown would not be suitable for working in conjunction with such a type of accumulator as there is no pressure drop to operate the piston A. The section through the back-pressure turbine shows no non-return valve in the piping leading to the heating system. Experience has shown this to be a necessity to prevent the low-pressure steam from flowing back into the turbine when the latter is at rest and the stop-valve in the heating steam pipe leaks or is not closed. I am glad that the author has gone so fully into the question of steam consumption correction factors. As a seller of turbines I have frequently found that buyers cannot discriminate between the correction factors employed when designing turbines and those employed when a turbine has been built for one set of working conditions. When the correction factors are smaller in the latter case, they do not think they are being fairly dealt with. I hope the figures given will serve as an enlightenment. In particular I would thank the author for his statement that the thermodynamic efficiency varies with the amount of superheat employed; consulting engineers and buyers in general are usually more or less in ignorance of this, although it is an established fact with manufacturers. I think most engineers, whose experience with steam turbine design and construction dates back some years, will agree that the developments and improvements which have taken Mr. Davis.

Mr. Davis.

place, have been chiefly brought about by practical results rather than by reason of theoretical research. As the author shows, the theory of the steam turbine was really first appreciated after a large number of very satisfactory machines had already been built. This being so, it is remarkable that the three-bearing design, which has been mentioned by the author and criticised adversely in the discussion on an isolated bad result (which has since been cured without departing from the three-bearing construction), should have met with such success in practice that one firm alone has built more than 1,200 such machines in size up to 20,000 k.w. The tendency on the Continent on the part of experienced impulse turbine and generator makers fully acquainted with theoretical considerations, is to depart from the design with four bearings and a flexible coupling in favour of three bearings and a rigid coupling even when the turbine and the generator are constructed by different makers. Such facts must clearly demonstrate that the latter design is in no way inferior to the former from the practical standpoint, which, after all, is the only one that really matters.

Mr. Pochobradsky.

Mr. B. POCHOBRADSKY (*communicated*): The author gives blading efficiency curves for single, 2-row, and 3-row impulse wheels. It is interesting to compare the efficiency of the 2-row wheel with the efficiency curve (Fig. B) published by O. Lasche in 1909.*

u/c_0.	$\eta_{A.E.G.}$	η_B.
	Per Cent.	Per Cent.
0·20	67·5	65·3
0·23	69·7	67·5
0·25	71·0	66·3
0·30	72·5	58·0

I have not sufficient particulars of the tests, the results of which are apparently the above-mentioned curves. For this reason it is not advisable to compare the absolute value of the efficiencies. It is only stated that the A.E.G. efficiencies are for dry saturated steam (for superheated steam still better efficiencies are to be expected) and on the assumption that the blading is designed for the maximum value of u/c ($u/c_0 = 0·3$ about). The only point which I would consider is the ratio u/c_0 for maximum, that is, for the author's curve $u/c_0 = 0·23$. For this ratio the A.E.G. efficiency is still increasing; even for $u/c_0 = 0·3$ (according to the curve) the efficiency is still increasing.

The character of the author's curve is in accordance with calculated curves published several years ago.† The basis for the

* G. Bauer and O. Lasche, "Marine Steam Turbines," translated by G. S. Swallow, London, 1911, p. 75.

† A. Stodola, "Die Dampfturbine," 3rd ed., 1905.

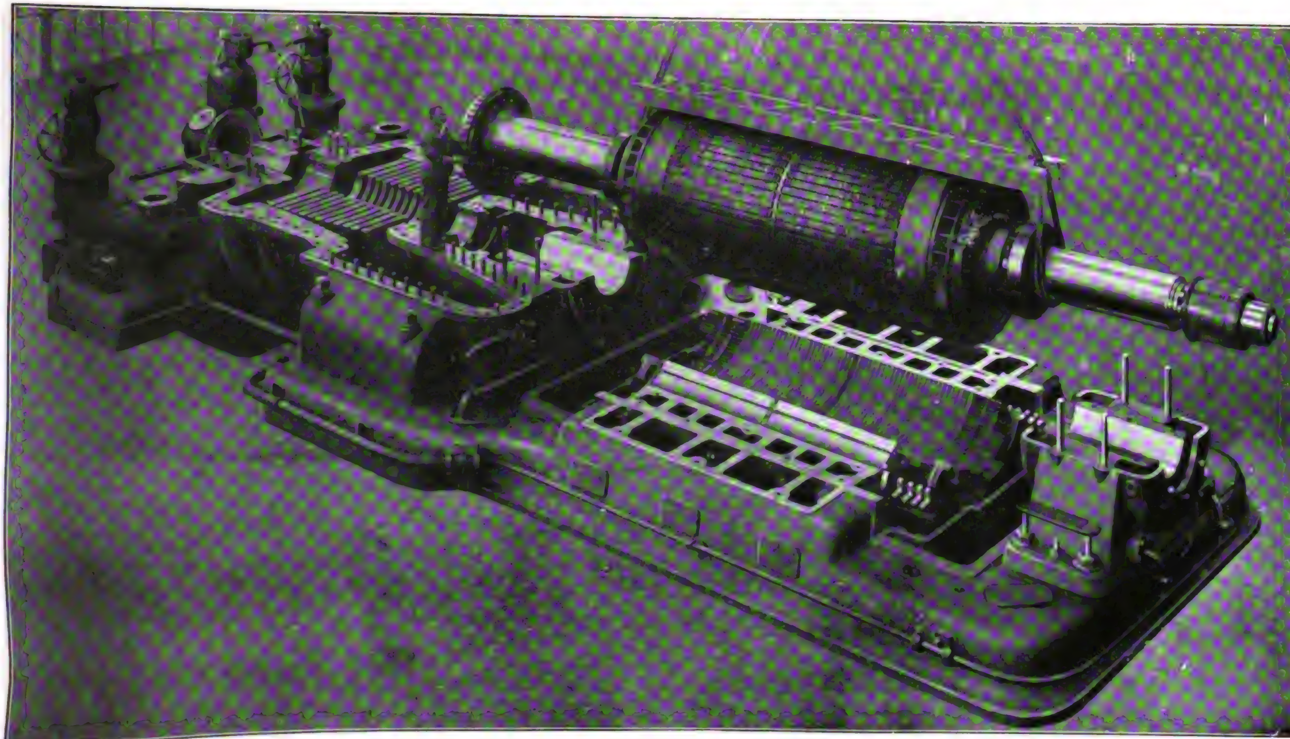


FIG. B.

Mr. Pochobradsky. Professor Stodola gave an example of a reaction Curtis turbine, built by the General Electric Company, demonstrating its advantages as compared with impulse Curtis wheels. The character of the A.E.G. curve seems to show that reaction is being used, and certainly means an improvement. It is obvious that reaction applied for a single, or three or more row, wheel would have a similar effect upon the character of the efficiency curve. This effect explains fully the reason which led to some velocity-wheel turbines being designed for $u/c_0 > 0{\cdot}23$—for instance, the General Electric Company's turbines for Chicago. On the other hand, we quite agree with the author that maximum blading efficiencies are considerably decreasing with increasing number of blade rows. This circumstance is the reason for the combination of one Curtis in the high-pressure and several single impulse wheels in low-pressure part, instead of a pure Curtis turbine. It would be interesting to compare the two different solutions of velocity wheels on the basis of tests with full particulars for the same conditions.

The corrections of steam consumptions for varying conditions are certainly very interesting to electrical engineers. They remind one very greatly of Professor Stodola's book ("Dampf-turbinen," pp. 212–225, 1910). I think this ought to have been mentioned by the author. Considering that it is very often difficult, if not impossible, to test the turbine under guarantee conditions, and that the corrections, although sometimes quite simple, often cause difficulties to both the purchaser and the maker, it would certainly be an advantage to adopt some standard corrections. The corrections given by the author will probably correspond to those generally used for standard turbines. They represent an average which is more or less correct for different types. But the differences for turbo-generators will be very small in the majority of cases. For extraordinary cases it is, of course, necessary to settle some rules for exceptions. I would mention one case. Suppose a turbine designed for a certain vacuum to have very high leaving losses on account of the output being very high for the type in question. In increasing the vacuum, the outlet steam velocity might attain its critical value. From this point, of course, any vacuum increase has no effect on the steam consumption. Generally speaking, however, standard rules for correcting the steam consumption are very desirable, as well as general standard rules for power stations, etc. The tendency of the development of steam turbines is demonstrated very clearly in the author's paper, which, on the other hand, is not very complete, nor fair, as to the different firms which have contributed to the development. There are practically two main types, Curtis-Parsons and Curtis-Rateau, on the European market. Other types have been successful too, but these two main groups are predominant. Considering that of late years turbo-generators are being built with high speeds, even for comparatively large outputs, it is to be expected that for this reason, and many others, the Curtis-Rateau turbine will successfully continue its development, and justify the extraordinary

progress made in the few years since the A.E.G. brought the first Curtis-Rateau turbine into the market. Mr Pochobradsky.

Mr. K. BAUMANN (*in reply*): Several of the speakers have complained that insufficient reference has been made to some of the most important designs of steam turbines manufactured in this country. In reply I must point out that I have unfortunately been unable to find descriptions published during the last few years of disc-and-drum turbines or of Curtis turbine designs originated in this country. Moreover, no change in the principle of the design of the Curtis turbine has been made during the last eight years, except that the vertical shaft has been replaced by the horizontal. This is referred to on page 783 of the paper. It must also be admitted that the matter dealt with in the paper is of a nature so comprehensive that it could not possibly be exhausted in a paper written primarily to inform electrical engineers of the recent developments and future possibilities of steam-turbine design, and not as a text-book for steam-turbine designers. I am glad, however, to take the advantage of this opportunity to complete the descriptions and to substantiate some of the statements which, for the reasons given above, had to be abbreviated as much as possible. Mr. Baumann.

High Superheat.—Mr. Stoney's remark that trouble due to high superheat is common both to the pure Rateau turbine and to the pure Parsons turbine is correct, but in the Rateau turbine the expansion would not be detrimental to the steam consumption to the same extent as in the Parsons turbine.

Disc-and-Drum Machines.—Mr. Stoney stated that the disc-and-drum turbine works under most favourable conditions for outputs from 750 to 1,500 k.w. at 3,000 revs. per minute, and later that it is useful for small outputs, say 500 k.w., at 3,000 revs. per minute. From this it would appear that, generally speaking, the disc-and-drum type is useful for all outputs up to 1,500 k.w. at 3,000 revs. per minute. This is quite reasonable, as for lower speeds, say 1,500 revs. per minute, the difference in the diameters of the Curtis wheel and the medium-pressure drum becomes too large and necessitates a very complicated design of casing which is exposed to deflection due to pressure and expansion due to temperature.

Blade Cutting.—The question of blade cutting in impulse wheels, due to high steam velocity, has been raised from time to time by people who are not favourably disposed to the use of velocity wheels, but this is mainly because they have had very little experience with them. The cutting action may be due to corrosion (chemical action) or to erosion (mechanical action). Both actions are very often combined, and both are more perceptible with wet than with superheated steam. Chemical action can, in all cases, be overcome by purifying the feed water, and mechanical action, according to my experience, does not take place for steam velocities actually used for combined turbines. The only two cases of erosion which I know of were due to the action of water which was not properly drained from the cylinder.

Disc Turbines for Large Outputs.—Mr. Stoney doubts my statement

Mr. Baumann.

that the disc turbine is the design for large outputs, and refers to the tandem turbine of 1,000-k.w. capacity supplied to Elberfeld, which, as far as I can make out, runs at 1,500 revs. per minute, and the eight tandem turbines of 6,000-k.w. capacity installed at Lots Road Power Station, which runs at 1,000 revs. per minute. I fail to see how these examples bear on the case, as both refer to turbines with small or moderate outputs according to the definitions given in my paper. The 6,000-k.w. turbine referred to as having caused a great saving in coal must, of course, be provided with a cast-steel high-pressure casing, as the growth of cast iron, with the consequent increase of the necessarily small clearances, would be very detrimental to the high economy. The calculations given for the maximum outputs obtainable refer to drum designs and disc designs, and the final result depends only on the greater strength of rotating discs as compared with drums, and is independent of the system used for the different stages of the turbine. It is self-evident, therefore, that a reaction turbine built in discs will have the same maximum output as ordinary impulse turbines. I do not agree, however, that caulked blades can be used for the same peripheral speeds and of the same length as the blades used at present in Rateau turbines. The stresses and the factor of safety in the latter can be calculated very accurately, and their reliability does not depend on the workman.

Low-pressure Turbines.—It is true that Parsons took out a patent on low-pressure turbines in connection with high-pressure engines in this country in 1894, but it was not the master patent, as patents on the same subject had been taken out by other inventors* before that time. The application of a low-pressure turbine to a high-pressure engine running continuously is, as pointed out in my paper, very limited, and the greatest scope for low-pressure and mixed-pressure turbines lies in their application to engines running intermittently. The opening up of this field was beyond doubt due to the pioneer work of Professor Rateau who invented, in addition to the Rateau accumulator, the mixed-pressure turbine in 1901 and the governor fitted to it.

Vacuum Corrections.—With regard to the corrections for vacuum, Mr. Stoney remarked that the efficiency of the Parsons turbines if properly designed for vacuum is the same for any vacuum. If properly designed means adding more stages for higher vacuum this is approximately true, but generally the standardisation of turbines does not allow of this, and it is necessary to calculate the turbines with the same number of stages independent of the vacuum, and the corrections have been given for these conditions, as clearly stated in my paper. For a constant number of stages the efficiency of each wheel decreases with increased heat drop, according to the curves given in Fig. 10, due to the decreased velocity ratio u/c. An increase in the vacuum

* Patents on this subject have been taken out in this country by Cordes and Locke in the year 1840. (See English Patent No. 8572, A.D. 1840, also United States Patent No. 2019 dated 29th March, 1841.)

Mr. Baumann.

from 28 in. to 29 in., for instance, increases the heat drop 9·5 per cent., and will therefore decrease the ratio u/c by about 5 per cent. If this ratio was $u/c = 0·35$ for 28 in. it would only be 0·335 for 29 in., and this would decrease the efficiency according to curve A (Fig. 10) from 74·3 per cent. to 72·8 per cent., which means a reduction in the theoretical correction of 2 per cent., *i.e.*, from 9·5 per cent. to 7·5 per cent. Further, an unavoidable reduction in the efficiency is due to the larger leaving losses with this higher vacuum—this correction, of course, depends to a very great extent upon the output of the turbine. For turbines with small outputs it is negligible, but it is considerable for turbines with large outputs at high vacua, as can be seen from Fig. 23. For a 3,000-k.w. turbine running at 3,000 revs. per minute the leaving loss would increase from 0·8 per cent. at 27 in. vacuum to 1·5 per cent. at 28 in. vacuum, *i.e.*, 0·7 per cent.; and from 1·5 per cent. at 28 in. vacuum to 4 per cent. at 29 in. vacuum, *i.e.*, 2½ per cent. For a 2,250-k.w. turbine this last figure would be about 1·6 per cent. This additional correction added to that given above would reduce the correction from 7·5 per cent. down to 6 per cent., and this figure, which refers to turbines for large outputs, has been given in the paper. For smaller outputs this figure should have been corrected, but was omitted in order to shorten the paper as much as possible.

The following is a complete list of corrections for turbines both with an increased number, and with a constant number of stages :—

Vacuum.		26–27 in.	27–28 in.	28–29 in.
		Per Cent.	Per Cent.	Per Cent.
Theoretical correction		5	6	9·5
Corrections for turbines with increased number of stages ...	Small outputs ...	5	6	9·5
	Moderate „ ...	5	6	9·0
	Large „ ...	5	6	7·5
Corrections for turbines with constant number of stages	Small outputs ...	4	5	7·5
	Moderate „ ...	4	5	7·0
	Large „ ...	4	5	6·0

Efficiency of Curtis Wheels.—In reply to Mr. Samuelson, who doubts the correctness of the efficiencies given in Fig. 10, I can only point out that the relative difference in the efficiencies given for Rateau wheels and velocity wheels, corresponds very closely to the curves published by other workers, *i.e.*, Professor Stodola and O. Lasche, of A.E.G.—in fact, by everybody who has had experience with both types of turbine. I do not hesitate to say that the time is not far distant when it will be

Mr. Baumann.

necessary for builders of pure Curtis turbines to manufacture the combined type of turbine in order to compete with other firms with regard to steam consumption. The results which have been published by manufacturers of pure Curtis turbines show certainly a very small difference in the steam consumption when compared with other types, in fact, they are better than we should expect, and it would certainly be of great interest to know the main particulars, *i.e.*, the number and diameter of the wheels, so as to render a check of the efficiencies possible.

Expansion of Wheel Bore.—I agree with Mr. Samuelson that the expansion of the wheel bore is a very important factor to be considered. The calculation of the expansion if the stresses σ_r and σ_t are known is very simple for those acquainted with the elementary theory of elasticity. It is given by the formula $\Delta r/r = (\sigma_t - \nu\,\sigma_r)/E$; where r = radius of the circle; Δr = increase in radius (expansion); $\nu = 0{\cdot}3$ for steel; E = modulus of elasticity. This formula shows that the expansion is practically proportional to the tangential stress in the bore of the wheel, so that the stress itself can tell us if any difficulties with regard to expansion are to be expected.

Nozzle Control Governing.—In spite of the assurance of Mr. Samuelson that the governor gear of the turbine made in Rugby is well known by its simplicity, I adhere to my statement which was confirmed during the discussion by engineers in charge of power stations. The simplicity of the governor gear as originated by the A.E.G. is only possible with their design, in which the high-pressure end cover, referred to on page 782, is made in one piece. This design allows of the nozzle being arranged in one set on one side of the thrust pedestal, which advantage may be one of the reasons for the retention of this design. It has, however, the great disadvantage of inaccessibility, referred to in the paper. In order to avoid this disadvantage a horizontal joint must be made right through the whole turbine as shown in Fig. 17. This design has now also been adopted by the A.E.G. for their 20,000-k.w. turbines, referred to on page 807 of the paper.* In this case the nozzles must generally be arranged in two or more sets, and the valve-gear then becomes more complicated. Another more important point which has to be considered is the necessity for the valves to be absolutely tight when closed, since a small leakage would reduce the theoretical advantage gained to zero, or even convert it to a loss.

Mixed-presssure Turbines.—The description of the mixed-pressure turbine given by Mr. Samuelson indicates at first sight a considerable advantage when compared with that shown in Fig. 30. It can be seen, however, that the advantage of this arrangement when adapted to the combined turbine is reduced to a negligible amount. It can only be used to advantage when using not more than two Curtis wheels in the low-pressure part of the turbine, the efficiency of which, as already pointed out, is so much below that of Rateau wheels that the difference is hardly balanced by the advantages stated above. Again, it is a

* A.E.G., Zeitung, March, 1912.

Mr Baumann.

simple matter to design a Rateau or a Parsons turbine, so that the full amount of low-pressure steam available can be utilised also on overload, if this be required for long periods, during which the full amount of low-pressure steam is always available. Taking the case mentioned by Mr. Samuelson and assuming a high-pressure consumption of 18 lbs. per kilowatt-hour we see that the low-pressure part of the turbine is to be designed for a steam quantity equal to $33 \times 1{,}000 + 18 \times 250 = 37{,}500$ lbs. steam per hour as compared with 33,000 lbs. per hour. When running on full load with low-pressure steam only, the steam will be throttled 12 per cent., which means an increase in the full-load consumption of 5 per cent.; this is smaller than the difference in the steam consumption of a pure Rateau turbine and a pure Curtis turbine, and the turbine has the advantage of giving 15 per cent. overload without the use of high-pressure steam and without the use of a low-pressure bypass valve—*i.e.*, with a very good economy. The advantage of reduced disc friction when running on low-pressure steam only is of little importance, as the disc friction itself is so small (averaging about 2 per cent.) that the decrease of the pressure in the high-pressure part would improve the economy only to the extent of 1 per cent. The splendid efficiencies obtained on mixed-pressure turbines of the type shown in Fig. 30 when running on high-pressure steam only, prove that fears with regard to the effect of too large nozzles in the low-pressure part are groundless. All the advantages referred to by Mr. Samuelson appear in the guarantees given to the purchaser for the different conditions, and in many cases on paper the machines appear to be economical, but we must not overlook the fact that the efficiency when running under mixed-pressure conditions is of the first importance as the machine is usually operated under these conditions in practice, and we shall show below that the arrangement discussed by Mr. Samuelson is less efficient when running under these conditions than the type of machine shown in Fig. 30. Let us assume the turbine to be running on full load and that only 20,000 lbs. of low-pressure steam is available. In the case of the arrangement mentioned by Mr. Samuelson, the low-pressure steam will be throttled to a pressure given by the ratio of the available low-pressure steam quantity to the normal quantity, *i.e.*, $20{,}000/33{,}000 = 0{\cdot}6$. The loss due to throttling can be calculated from the increase in steam consumption due to decrease of pressure and the improvement in the efficiency due to superheat obtained by throttling the steam. According to the remarks made on page 840 of the paper, the steam consumption for low-pressure turbines increases 4 per cent. for each 10 per cent. decrease in pressure, and the increased superheat due to throttling decreases the steam consumption 0·5 per cent. for the same difference in pressure. Throttling of 10 per cent. increases the steam consumption therefore $4 - 0{\cdot}5 = 3{\cdot}5$ per cent., and for the case mentioned above, throttling to the extent of $\dfrac{1{\cdot}0 - 0{\cdot}6}{0{\cdot}8} = 50$ per cent., would cause an increase in steam consumption of $3{\cdot}5 \times 5 = 17{\cdot}5$ per cent., *i.e.*, an increase of from 33 lbs. per kilowatt-hour to 39·4 lbs. per kilowatt-hour.

Mr. Baumann.

This agrees satisfactorily with the figure which can be obtained when correcting the consumption according to the available heat-drops :—

> Heat drop for 14·2 lbs./square inch absolute dry saturated and 28 in. vacuum: 92 calories per kilogramme.
> Heat drop for 8·5 lbs./square inch absolute 20° F. superheated and 28 in. vacuum: 76 calories per kilogramme.
> Corrected consumption $= 33 \times 92/76 = 40$ lbs. per kilowatt-hour.

With this consumption the available steam quantity of 20,000 lbs. per hour will give an output of $20{,}000/40 = 500$ k.w. The remaining 500 k.w. must be made up by high-pressure steam. Assuming a steam consumption of high-pressure steam of 20 lbs. per kilowatt-hour, the high-pressure steam consumption will be 10,000 lbs. per hour. Under these conditions the different wheels work at the following partial loads :—

First wheel	Half load.
Second wheel (high-pressure portion) ...	Half load.
Second wheel (low-pressure portion) ...	Half load.
Third wheel	About ¾ load.

In the case of the mixed-pressure turbine given in Fig. 30 the position is different. As the high-pressure steam is mixed with the low-pressure steam the whole of the low-pressure part is working at about ¾ load, and the pressure in front of the low-pressure part will be considerably higher than in the case mentioned above; the low-pressure steam consumption will therefore be considerably less. With the total quantity of 28,600 lbs. per hour passing through the low-pressure part, the pressure drop through the low-pressure valve would only be 15 per cent., which means an increased low-pressure steam consumption of only 5·3 per cent. as compared with 17·5–19 per cent. found above. The low-pressure steam consumption being 34·8–35 lbs. per kilowatt-hour, 20,000 lbs. steam per hour would develop $20{,}000/35 = 570$ k.w., *i.e.*, 14 per cent. more than with the arrangement put forward by Mr. Samuelson. The high-pressure steam would only have to give 430 k.w., and further, the high-pressure steam consumption expressed in pounds per kilowatt-hour would be smaller, as in this case the high-pressure steam will work in the whole low-pressure part on ¾ load, whereas in Mr. Samuelson's scheme it will work on half load on the first low-pressure wheel and on ¾ load on the last wheel only. Even assuming the same steam consumption for both cases—*i.e.*, 20 lbs. per kilowatt-hour—the consumption of high-pressure steam would only be $430 \times 20 = 8{,}600$ lbs. per hour, or 1,400 lbs. per hour less than the above, which is about 8 per cent. of the full-load high-pressure steam consumption. The improved economies obtainable with Mr. Samuelson's scheme refer, therefore, mainly to guarantee conditions. For practical working conditions, however, where the turbine runs generally as a mixed-pressure machine its disadvantages as compared with the type shown

Mr. Baumann.

in Fig. 30 are great. This disadvantage is often not noticed owing to the difficulties of testing mixed-pressure turbines when running with mixed-pressure steam. In order to obtain good economies with mixed-pressure turbines, using at the same time both low-pressure and high-pressure steam, it is necessary to mix the low-pressure steam with the high-pressure steam as soon as possible, *i.e.*, at the low-pressure inlet, and not after the first low-pressure stage as proposed by Mr. Samuelson. The remarks with regard to test results obtained on mixed-pressure turbines are correct. The fact, however, remains that the results of the Curtis-Rateau turbine given in Table VIII. (Test No. 3c) show that this turbine is more efficient than the Curtis turbine mentioned. This will be realised when considering the large pressure-drop through the governor valve, which distinctly shows that the turbine was not running at its most economical load—*i.e.*, full load. For that load the throttling through the valve would not be more than 10 per cent. of the absolute pressure—*i.e.*, from 15·1 lbs. per square inch absolute to 13·6 lbs. per square inch absolute, whereas during the test the pressure after the valve was only 12 lbs. per square inch absolute. For full load the losses due to a throttling of 10 per cent. would only be 3½ per cent., so that a turbine efficiency before the governor valve of 78·2 per cent. could have been obtained instead of 74·6 per cent. and the total efficiency would be 73·1 per cent. Allowing for 104° F. higher superheat, a correction of 4·5 per cent., we obtain an efficiency of 69·8 per cent. as compared with the efficiency of 68·2 per cent. obtained by the Curtis turbine in question. My statement with regard to the best efficiency realised on mixed-pressure turbines must therefore be allowed to stand.

Comparative Efficiencies.—Mr. Kaula states that the disc-and-drum turbine should be better than the disc turbine for large outputs. I do not agree with the first reason he gives in support of this statement, that because the skin friction losses for disc turbines are considerably larger than those for drum turbines, special allowance should be made. This allowance is very small as the disc friction loss in a disc turbine is extremely small, generally not more than 2 per cent., and this cannot be of any importance in view of the leakage losses over the tips of the blades in reaction turbines, which are hardly ever smaller than 5 per cent., and very often more than 10 per cent. Then as regards the second point mentioned by Mr. Kaula, that a solid drum should be treated as a disc without a hole, I must point out that the danger from lack of homogeneity is much more serious for rotating drums than for drawn bars, for instance, stressed in the direction of the grain; also that the bursting of a solid rotor would be far more disastrous than the expansion of a drum or of a disc which would expand equally until it touched the casing, thus shutting down the turbine. With regard to Mr. Kaula's remarks on the efficiencies of the turbines, it would have been more satisfactory if he had substantiated his statements by giving some steam consumptions which have been obtained on the disc-and-drum type of turbine.

Mr. Baumann.

Steam discharged by Air-pumps.—Mr. Kaula states that test results generally do not take into account the amount of water discharged by the air-pump, and that a distinct difference should be made between wet and dry air-pumps. Although this point does not come within the scope of my paper, I consider it worth while to devote a little time to it in view of the confusion existing among engineers with regard to the quantities of steam condensed in the air-pump. Mr. Kaula divides, for the purpose of explanation, the air-pumps into two main types: wet air-pumps and dry air-pumps. Wet air-pumps are those which pump the air and extraction water by means of the same piston, and the dry air-pumps those which pump the air and extraction water by means of separate pistons. In order to show clearly the differences in the steam quantities pumped by the different types, I prefer to divide these types as follows: (1) dry piston air-pumps; (2) wet piston air-pumps; (3) piston air-pumps sealed with cold water; (4) rotary pumps.

1. *Dry Piston Air-Pumps.*—The inlet volume of the mixture of steam and air pumped by these pumps is approximately constant, practically independent of the vacuum, and is given by the capacity of the pump. The air quantity and the steam quantity can easily be calculated from the temperature of the mixture in front of the pump. I have had the opportunity of investigating this matter very closely on an installation consisting of a 1,500-k.w. turbine, including surface condenser, dry air-pump, and separate extraction pump, installed at Mülhausen, which was tested in March, 1907, by Professor Stodola. The steam quantity discharged by the air-pump was found to be not more than about 50 lbs. per hour, which on a full-load consumption of 25,000 lbs. per hour means a correction of 0·2 per cent. of the steam consumption as measured by the discharge of the extraction pump.

2. *Wet Piston Air-Pumps.*—For these pumps the conditions are similar to those stated above, but the water is separated from the air at the outlet to the pump, one part of the 0·2 per cent. would be condensed in the pump, and a considerably smaller amount of steam would escape with the air as stated by Mr. Kaula.

3. *Piston Air-Pumps with Cold Water Seal.*—For these pumps the conditions are quite different. If the water is properly mixed with the mixture of air and steam drawn from the condenser, the mixture will be cooled down to a temperature slightly above the cooling water temperature, and thereby the greater part of the steam will be condensed. In this case the volume of air actually pumped by the piston pump will be constant, as given by the cylinder dimension, but the volume of the mixture flowing from the condenser to the pump will be considerably larger and will depend upon the quantity of steam condensed by the cooling water. The same effect is obtained by—

4. *Rotary Air-Pumps.*—In these pumps the cold water is used as seal water, which acts at the same time as an air cooler. It is very difficult to calculate exactly the quantity of steam drawn from the condenser, since this depends upon the relative capacity of the condenser and the air-pump, as will be seen from the following explana-

Mr. Baumann.

tion: Assume, first of all, a very large surface condenser working in conjunction with an air-pump of relatively small capacity. The condenser in this case will easily be able not only to condense the steam, but also cool to a very great extent the air before leaving the condenser. The mixture flowing into the air-pump will contain a relatively small amount of steam, an amount similar to that obtained with the dry air-pump, or even less. On the other hand, a condenser which is too small to condense the steam quantity may be required to work in conjunction with a very large air-pump which is able to create a very high vacuum, whereas the vacuum obtained in the surface condenser may be low. The difference in the vacuum will cause a large amount of steam not condensed to flow into the air-pump, which will now work partially as a jet condenser. The quantity of steam condensed by the rotary air-pump will depend upon the difference in the vacuum in the surface condenser and that in the air-pump, *i.e.*, the relative capacity of the surface condenser and the air-pump, and upon the size of the pipe connecting the two. In normal cases where the condenser and air-pumps are properly calculated, the steam condensed in the air-pump will not exceed ½ per cent. at full load and will only be more when the plant is heavily overloaded. The very fact that too much steam is being condensed by the air-pump indicates that the surface condenser is too small, or that the air-pump is too large. The vacuum depends in this case more on the surface condenser than on the air-pump, and the drawing of steam into the air-pump can easily be overcome by reducing the pipe diameter connecting the surface condenser and the air-pump, or by simply throttling the mixture by a sluice valve, without affecting the vacuum in the surface condenser to any appreciable extent. For steam consumption tests it is, of course, a simple matter to measure the steam quantity pumped by the air-pump by measuring the increase in the water-level in the sealing water tank. For normal conditions it has, however, always been found that it is an almost negligible amount.

Marine Turbines.—Mr. Watson's remark that marine engineers are as keen on high efficiencies as electrical engineers in power stations is quite true, but unfortunately the conditions to be met in the case of marine turbines are not as favourable for high efficiencies as for land turbines, which, when coupled to electric generators, can be run at much higher speeds. In order to obtain best overall efficiency of turbine and propeller, the speed of marine turbines is to be much lower; they are approximately: For destroyers, 700 revs. per minute for powers up to 20,000 B.H.P.; second-class cruisers, 500 revs. per minute for powers up to 20,000 B.H.P.; battleships, 300 revs. per minute for powers up to 30,000 to 80,000 B.H.P. These low speeds, in combination with the light weight required, make it impossible to design the turbines for maximum efficiencies, and in order to decrease the number of stages it is necessary to use velocity stages with three or even four rows of blades. The efficiency of a marine turbine is therefore not so good as a turbine of large output running at a very high speed which can easily be designed for maximum efficiency.

Mr. Baumann.

Test Results.—With regard to the efficiency of 67·9 per cent. of the Curtis-Rateau turbine given in Table V. (No. 27), and referred to by Dr. Rosenberg, I should like to add that this turbine was intended first to work in conjunction with the existing cooling towers, and was therefore designed for a vacuum of 27½ in. Later on it was decided, however, to obtain cooling water from a river, so that a considerably higher vacuum could be obtained. The vacuum during the tests was nearly 28½ in. The difference in efficiency can be obtained by comparing the correction for a given turbine—which is, according to Table VIII., 4·4 per cent. for turbines designed for 27½ in. vacuum—with the correction for turbines designed for the particular vacuum, as stated on page 831, to be 5·5 per cent. between 27½ in. and 28½ in. vacuum. The efficiency which would have been obtained if the turbine had been designed for 28½ in. is therefore 1·1 per cent. higher than 67·9 per cent., *i.e.*, 68·6 per cent., and would be higher than that given for the 6,000-k.w. turbine mentioned in Table VI. (No. 28). Unfortunately I am not in a position to apply the correction outlined in paragraph 9 of my paper to the test results given, as not sufficient data are available with regard to the designs of the different turbines, which are necessary to fix the vacuum corrections for instance.

Balancing.—Mr. Sanders states he does not agree with my remarks on page 805 concerning disc and ordinary drum constructions, and points to the difference in balancing drum turbines and balancing disc turbines. This agrees quite well with what I said on page 807 in Section V.: "In this matter the disc type of turbine has a very considerable advantage over the drum, in that its critical speed can be calculated with ease, and certainty and that it can be balanced by statical methods."* My remarks given on page 805 do not refer to any advantage with regard to balancing, but deal only with the relative strength of discs and solid drums. I quite agree, however, with Mr. Sanders that the advantages with regard to the balancing of disc turbines, as compared with drum turbines, generally are very important, as by using discs a great deal of trouble can be avoided. The other trouble which Mr. Sanders referred to, as being due to the critical speed of the discs, can easily be overcome when the critical speed is known. The calculation of the critical speed is, however, too complicated, and cannot be made sufficiently exact. As its investigation would, in addition, be too elaborate and of no great interest for electrical engineers, it was intentionally not mentioned in the paper.

Measurement of Condensed Water.—In connection with Mr. McKenzie's last remark, I should like to point out the desirability of stating in all reports of tests made on steam turbines, the manner in which the tests have been carried out, especially with regard to the methods of measuring condensed water. In my opinion, the only exact method of measuring condensed water for steam consumption tests is the weighing of the water or the measuring of it by calibrated tanks. Any other

* The latter part of this sentence was omitted in the proof, but was corrected when reading the paper.

methods, as, for instance, measuring by means of a weir or by an ordinary water-meter or steam-meter, are not sufficiently accurate although they may be of great use for registering purposes. I have in mind one case of a 5,000-k.w. set where a difference of 7 per cent. was obtained, although all precautions with regard to adjustment of meters, etc., were taken to obtain exact results. Mr. Baumann.

Blade Corrosion.—I cannot agree with Mr. Paton's theory of blade corrosion. It is true that steam highly superheated dissociates; its dissociation starts at about 950° C. It is also true that "Heat" is the expression for movement of the molecules, the velocity of which can be calculated from the expression $c = \sqrt{3\, p/\rho}$, where c = velocity in metres per second; p = pressure in kilogrammes per $m.^2$; ρ = density in kilogrammes per $m.^3$. The velocity of the molecules of steam at atmospheric pressure and 212° F. would be therefore about 700 metres per second; at the temperature of dissociation, *i.e.*, 950° C., it would be about 1,300 metres per second. This relative velocity is present in steam at rest as well as flowing; and the molecules moving in all directions the value calculated is a measure of the velocity with which they collide. It is obvious, therefore, that the phenomena of a drop of composite viscous matter travelling through space at a high velocity cannot be applied to flowing gas in which the relative velocity of the molecules is much higher than their mean velocity in the direction of flow, and where this relative velocity, which would cause dissociation, is independent of the latter. Mr. Paton's theory does not agree, therefore, with the molecular theory, and moreover, it does not agree with what occurs in practice. According to his theory, corrosion would be more perceptible with highly superheated steam than with saturated steam, which is not the case. It is therefore obvious that dissociation of the steam has nothing whatever to do with the cutting of the blades, and that the true explanation is the action of the heavy water particles thrown against the metal at a high speed.

Reducing Turbines.—The steam consumptions given for the reducing turbine on page 823 refer to the working of the turbine on full load when no steam is passing through the low-pressure part of the machine, the high-pressure steam entering the turbine being dry saturated, steam pressure 190 lbs. per square inch. The efficiency obtainable under these conditions is 60 per cent. and more.

Efficiency of Rateau and Curtis Wheels.—Mr. Livingstone mentioned efficiencies of Rateau-Curtis wheels—I assume that he means Rateau wheels. The efficiencies given include losses due to steam friction of the wheels, windage losses of the blades, and the losses in the main glands and diaphragm glands and bearings. The values which have been allowed for these losses vary, of course, to a great extent with the size of the turbine, and the calculation of same would have necessitated the writing of a text-book, which was not my intention in writing the paper. The values taken correspond to outputs of turbines equal to the higher limit given for moderate outputs, and can be

Mr. Baumann.

estimated from Fig. D, which gives in addition to the total efficiency of the turbine, the calculated blading efficiencies, not including the losses stated for the different turbines. From my remarks that the efficiencies given for the Rateau wheels correspond to test results obtained on Rateau turbines, it is evident that the improvement due to the utilisation of the outlet velocity is included in the efficiencies, as actually this improvement will exist although it need not be considered in the calculation of the turbine in any other manner than by an additional coefficient found by experience. With regard to the curves given in Fig. D, I should like to give the following explanation :—

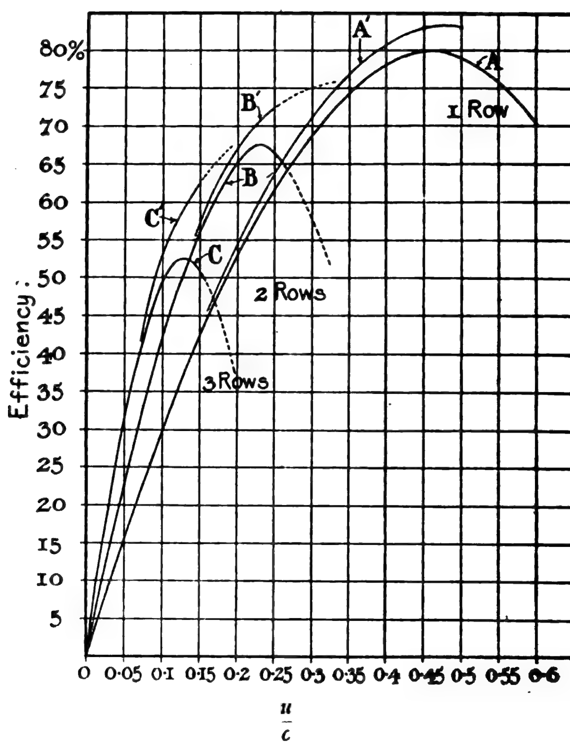


FIG. D.

1. *Rateau Wheels.*—As already stated, curve A′ gives the calculated blading efficiency. The difference in the value of the efficiencies given by curves A and A′ corresponds to disc friction losses, gland losses, and bearing losses for a turbine of a high moderate output; it is for the ratio $u/c = 0{\cdot}46$ mentioned in my paper $83{\cdot}3 - 80/80 = 4{\cdot}1$ per cent. A further allowance of 4 per cent. was made for increased friction and leakage losses in the high-pressure part of the turbine (page 781).

2. *Curtis Wheels with two Rows of Blades.*—The blading efficiency is given by curve B′, which shows increasing efficiency with increasing ratio u/c up to $u/c = 0{\cdot}35$. For $u/c > 0{\cdot}25$ the blading dimensions become impracticable on account of the great increase of the blade heights for the second row of moving blades. This causes an additional increase of losses due to windage, which will become very serious if the wheel is rotating in steam of, say, atmospheric pressure. Curve B shows the effect of this, representing the blading efficiency of a high-pressure velocity wheel including windage losses. I used for my paper the same curve as representing the efficiency of a Curtis turbine, as the difference in the two efficiencies B′ and B, for the ratio $u/c = 0{\cdot}23$ mentioned in my paper is $(70{\cdot}5 - 67{\cdot}5)/70 = 4{\cdot}3$ per cent.—*i.e.*, about the same as that allowed for Rateau wheels. Curve B for a Curtis turbine, with three wheels, would probably show a maximum efficiency for a ratio u/c above that mentioned, but the difference in the actual values of the maximum efficiencies would be very small. Mr. Baumann.

3. *Curtis Wheels with three Rows of Blades.*—The blading efficiency is given by curve C′, which shows increasing efficiencies up to a ratio $u/c = 0{\cdot}2$. For $u/c > 0{\cdot}15$ the blading dimensions become impracticable on account of the great increase of the blade height for the last rows of moving blades. The additional windage losses may be very considerable when the wheel is rotating in high-pressure steam as it usually does. The influence is shown by the difference of the efficiencies represented by curves C′ and C, which latter has been drawn out for a specific case of a high-pressure turbine for light outputs. In the case of condensing turbines consisting of only one wheel the influence of the windage losses would be considerably smaller, but, on the other hand, the blading efficiency would be considerably less than that given by curve C′ which has been calculated for a back pressure condition—*i.e.*, with considerably smaller steam velocities. Those to whom the difference in the two efficiencies as given by the two curves $u/c = 0{\cdot}13$ appears too large may reduce it. The main fact, which I intended to show, remains that the maximum obtainable efficiency of a Rateau wheel is 10 to 15 per cent. better than that of a Curtis wheel with two rows of blades, and 30 to 45 per cent. better than that of a Curtis wheel with three rows of blades. The exact value depends on so many conditions—steam pressure, steam velocity, peripheral velocity, back pressure, length of blades, output of turbine, etc.—that they could not possibly be referred to in this paper.

Stresses in Discs.—I cannot agree generally with Mr. Livingstone's remarks with regard to the stresses in the periphery of the disc or the ring and the disc itself. The exact calculation of discs will always show that it is a relatively simple matter to keep the stresses at the periphery low, whereas it is more difficult to decrease the stresses at the centre of the disc. This may not, of course, apply to inferior designs of blade fastening—for instance, in grooves with loose rings, etc.—whereby

Mr. Baumann.

additional bending stresses are involved, which are difficult to keep within reasonable limits.

Stresses in Blades.—Bending stresses due to the force of the steam can, even for the longest blades, be kept easily within 10 per cent. of the stress due to the centrifugal force, by using for the longest blades a blade section with a larger width, say 1¼ in. instead of 1 in. The bending stress for impulse blades is relatively smaller than for reaction blades, as for the latter the distance between the extreme point and the neutral axis is relatively larger than on an impulse blade, which is much better proportioned with regard to resistance against bending. The additional correction is, for all practical purposes, so small that it is not necessary, and it was not my intention to discuss it. The statement that "a disc turbine can be made for twice the output of a drum turbine other conditions remaining the same" is obviously only approximate, and it is evident from the investigation given in the paper that this figure may be even enlarged by using discs of a stronger design. That the disc turbine is the turbine for large outputs is a statement which can be verified by anybody who is able to follow the investigation.

When reading the paper I referred to the work done by Professor Dunkerley, whose investigations with regard to critical speeds are certainly of great value. The discrepancies in Table IV., Test No. 26, are due to an oversight when copying the tables; the pressures after the governor valves were given in absolute pressures instead of gauge pressures. The additional discrepancies have been eliminated in the final proof of the paper.

Large Outputs of Turbo-generators.—Mr. Davis's interesting remarks with regard to the maximum outputs of turbines running at 3,000 revs. per minute, made by the A.E.G., show the tremendous development of the maximum output of turbo-generators for that speed which has taken place during the last few years. Unfortunately the development referred to has not been so rapid in this country, which is mainly due to the cautiousness of purchasers of turbo-generators and their reluctance to try machines of high output running at relatively high speeds.

Emergency Valves for Mixed-pressure Turbines.—Separate combined low-pressure emergency and stop-valves are used in connection with mixed-pressure turbines up to 2,000-k.w. capacity. For larger outputs the governor valve is closed in case of emergency by cutting off the oil supply to the relay governor. This is possible, as the oil pressure is exerted only on the underside of the power piston against a strong spring placed on top of same, which tends to close the valve as soon as the oil pressure underneath the piston is released. In addition a vacuum-breaker is usually fitted. Mr. Davis's remarks that non-return valves are necessary in connection with reducing turbines agrees with our experience.

Three-bearing Design.—I do not quite agree with Mr. Davis's statement with regard to the influence of theoretical research work on the development and improvement of steam-turbine design. Whereas it is

true that the theory was developed after satisfactorily running machines were installed, it is also certain that the rapid development of steam-turbine design is largely due to the fact that theoretically trained engineers were available to utilise the practical experience gained on these machines to the fullest extent. I think that the firm which Mr. Davis represents, and which is well known for its research work published from time to time, is a splendid example to prove this statement. I do not consider that the remark made during the discussion with regard to the difficulties experienced with the three-bearing design was intended adversely to criticise it in general. It would have been very interesting if Mr. Davis had confirmed that the difficulties met with were of the nature referred to in the paper. This would then have shown beyond doubt that the three-bearing design is not only superior to the four-bearing design from a practical standpoint, but that it is also quite practicable from a theoretical point of view, as I intended to show in the paper. I agree with Mr. Davis that the adoption of the three-bearing design will be more general in the future. Mr. Baumann.

Efficiency of Curtis Wheels.—Mr. Pochobradsky thinks that the difference in the character of the efficiency curves given in Fig. 10 and that given by Lasche is due to the application of reaction in Curtis wheels. This is not the case, as is clearly shown by curves B′ and C in Fig. 10A, which represent blading efficiencies of Curtis wheels calculated without reaction, but for the most efficient blade-angles. These curves show increasing efficiency up to the maximum ratios u/c given. The nature of curves B and C, given primarily for wheel efficiencies, is solely due to the effect of the ventilation losses, as referred to in the paper. On page 780 I stated clearly, "The actual maximum efficiency and the ratio u/c at which it is obtained depends mainly on the inlet angle and the ventilation losses of the wheel." This obviously not only refers to Rateau wheels, but also to Curtis wheels. It is true that by applying reaction the efficiency can be slightly improved for higher ratios u/c; experience shows, however, that in order to avoid excessive leakage only a small reaction can be applied, and this would not appreciably affect the curves B′ and C′ given for blading efficiencies. The remarks made by Mr. Pochobradsky on this subject are therefore at least misleading.

FLASHING-OVER IN COMMUTATOR MACHINES: ITS CAUSE AND PREVENTION.

By W. W. FIRTH, M.Sc.

(*Paper received 16th January, received in final form 19th February, and read before the* NEWCASTLE LOCAL SECTION, *11th March*, 1912.)

By the term flashing-over is meant the formation of an arc with explosive violence between the brushes of a commutator machine subjected to abnormal conditions of load. In every case the flash-over appears to be associated with high-current density in the brushes and excessive sparking. The arc forms a low-resistance path between the brushes, and the machine is virtually short-circuited as long as the arc exists. The arc is carried away from the commutator surface chiefly by the magnetic action of the leakage flux, and is finally broken at the outer portions of the brush-gear. In motor or converter cases, however, the circuit breaker may operate, and the arc is then extinguished by the withdrawal of the power.

Of all machines the converter is most subject to flashing-over, the usual cause being a short circuit on the direct-current side. It also occurs frequently in motors subjected to excessive overloads or to accidental breaking of the field circuit; it seldom occurs in generators, probably for the reason that armature reaction on short circuit greatly reduces the voltage across the segments.

In multipolar machines the flash sometimes extends around the circumference of the commutator, but as a rule is confined to certain pairs of brushes, a reason for which is suggested later. Flashing-over is a source of considerable anxiety to engineers because of the danger to attendants and the damage which usually results to the machine itself. The brush-gear is generally badly damaged, and often the machine is put out of commission for repair. A remarkable feature of the phenomenon is that the commutator is seldom, if ever, in the slightest degree injured in spite of the fact that the flash starts at its surface.

A valuable clue to the cause of flashing-over is afforded by a fact previously mentioned, that it is always associated with heavy initial sparking at the brushes. This may occur at any load, and depends upon the setting of the brushes; a machine set to run sparklessly at full load will probably not flash-over at full load, but will do so on light load if a short circuit develops in either case.

Now there are only two possible reasons for an arc forming between the brushes; either an abnormal rise of voltage or a decrease of resistance.

With regard to the former, it is conceivable that a large induced voltage may be generated in the armature by the sudden reduction of the current when a short circuit clears, but the following calculation shows that such a result is very unlikely with the small inductances of commutator machines. In the motor on which the experiments of this paper were carried out there are thirty-three commutator segments between each pair of brushes, the thickness of the mica insulation being 0·075 cm., giving a total thickness of mica to be bridged over of 2·48 cm.; taking the low value of 20,000 volts per centimetre the necessary flash-over voltage is 49,500. Now the induced voltage is $L\frac{di}{dt}$, where L is the coefficient of self-induction of the armature between a pair of brushes; the value of L measured by alternating current with the field unexcited is 0·031 henries, and the maximum rate of change of current during flash-over measured on the oscillogram Fig. 2 is 8,000 amperes per second, from which the maximum induced voltage—

$$L\frac{di}{dt} = 248 \text{ volts.}$$

Further evidence that the flash-over is not due to a rise of voltage at the brushes is that if it existed the insulation of the armature would almost invariably be broken down, a result which does not occur in practice. This remark also applies to the possibility of a surge.

There is left only the second alternative, namely, the establishment of a conducting path between the brushes. Here again there are two alternatives to consider, the path may consist (*a*) of carbon particles liberated from the brushes by excessive sparking, or (*b*) of a series of local arcs across the segments. The former is somewhat discounted by experiments carried out on a model commutator section composed of two copper bars insulated by a layer of mica of the usual thickness; the bars were kept at a potential difference of about 20 volts, a value in excess of that usual in practice. Carbon dust was sprinkled across the mica, but no short-circuiting was observed even when the carbon was heated, though it was proved that the voltage was sufficient to maintain an arc between the bars when once started by drawing a carbon rod across them; the latter point explains the flashing-over of old turbo-alternators with wire brushes. When a wire worked loose and bridged the segments some distance in advance of the brushes, an arc was started across each pair of segments which was afterwards maintained by the generated coil voltage; some such action as this may take place with carbon brushes subjected to rapid disintegration by excessive current density.

Consider now the possibility of the production of local arcs between the segments by imperfect commutation. With excessive current in

the armature coils the reversing field is weakened and the work of commutating the increased current is thrown on the brush contact resistance. Under these circumstances it is certain that commutation will not be complete by the time the leading segment leaves the brush, and in extreme cases the coil may be thrown into series with the advanced side of the armature when it is carrying current in the opposite direction to that in the armature.

This results in the formation of an arc between the leading segment and the brush tip which may still persist between the segments when the insulation is clear of the brush. The main current to or from the brush must pass through this arc, and a little consideration will show that it is in the same direction in the arc as the unreversed coil current. After this stage the conditions in a motor differ considerably from those in a generator or converter.

In the motor the coil short-circuited by the arc has left the reversing field and is moving into one of opposite sign under the succeeding pole-tip. Providing that the arc still exists, the generated voltage of the coil is now in the same direction as the short-circuit current with the consequence that the arc is maintained until it reaches the next brush. This action will take place with every coil on the armature, and results in a chain of arcs extending from brush to brush; the time taken to establish the short circuit is that of the revolution of the armature through a brush spacing. If the circuit breaker operates in a smaller time than this no flash-over can take place.

In the generator and converter the coil carrying the short-circuiting arc is subjected to an increasing reversing field as it passes under the pole. Whether the reverse current can exist over this period depends upon the initial magnitude of the current, the time constant of the circuit, and the value of the reversing voltage; in cases of heavy short circuits it is probable that the arc will be maintained when the coil has moved some distance under the pole and may even exist when the next brush is reached.

As to which of these two theories is the correct one, there are no direct means of experimental proof, but it is likely that both agencies are concerned, imperfect commutation as a primary cause and carbon dust as a secondary one; probably the function of the dust is to reduce the resistance of the arcs over the mica insulation. That carbon dust has some influence in producing flash-over is supported by observations on a 7½-H.P. 450-volt Westinghouse motor loaded with a direct-coupled 100-volt 50-ampere generator. Flash-over could be produced when desired by short-circuiting the fully loaded generator through a 40-ampere fuse. The flash was always present at the upper surface of the commutator where the carbon dust is held on by gravity, but none were observed on the lower surface where the carbon dust can fall clear. Further evidence is that when the commutator and brushes had been well cleaned, flashing-over could not be produced until the machine had run for some time afterwards.

To reduce the damage to the brush-gear during the experiment,

Fig. 1.

conducting horns were attached to the two upper brush-holders with their free ends extended well beyond the frame of the machine and about 6 in. apart. Examination of the horns showed that the arc had travelled to their extreme points.

Fig. 1 is a reproduction of a photograph taken during an experimental flash-over, from which the vicious character of the flash may be observed.

Fig. 2 is a copy of a photographic record of current and voltage to the motor at the time of flash-over, from which it is quite clear that the flash is not started by a voltage rise, and is therefore due to the second cause, viz., a fall of resistance across the surface of the com-

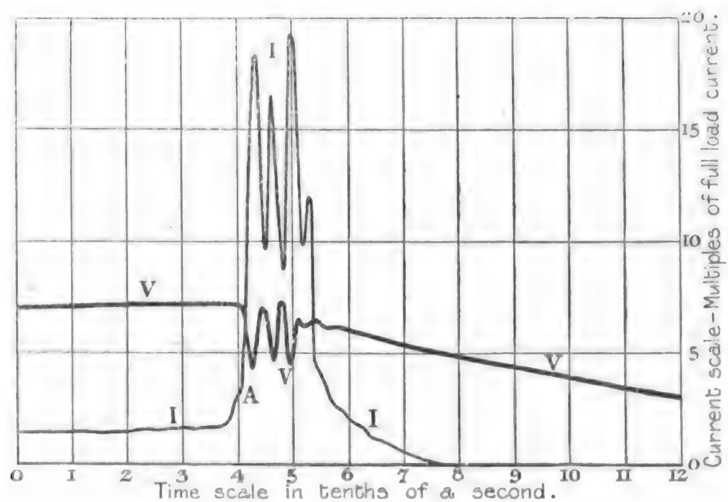


FIG. 2.

mutator. The establishment of such a conducting path between terminals across which a voltage of 480 is maintained is quite sufficient to start a current which instantaneously develops into a short circuit. The arc is then blown out by the leakage flux, but another one is at once started unless the short-circuit has cleared; a succession of flashes occurs so long as the short-circuit lasts.

In the voltage record of Fig. 2 there are large fluctuations below the normal voltage terminated by a falling line as the machine comes to rest, the main fuse of the motor having blown during the short circuit.

A distinct change in the slope of the current curve will be noticed at A, which point probably represents the instant of flash-over; it is of importance to the theory of progressive short-circuit to note that the time measured on the oscillogram from the bottom bend up to A closely corresponds with that required for a segment to move from one brush to the next.

Until the fuse blows the arc is maintained by the supply mains, and afterwards by the energy stored in the revolving armatures. The maximum current recorded on Fig. 2 is nineteen times full-load current, and the energy absorbed is about 7,500 ft.-lbs.; the total time of flash-over measured on Fig. 2 is 0·4 second. The ripples in both voltage and current appear to be due to the varying length of the arc as it passes over the irregularities of brush-gear and horns.

Prevention of Flashing-over.—The real solution of the problem of flashing-over is in the design of machines with good commutation and with an ample allowance of insulation between the segments. In machines which are subject to the trouble, either the current must be prevented from attaining an excessive value, or, the travelling arcs and liberated carbon particles must be prevented by mechanical means from moving across the surface of the commutator.

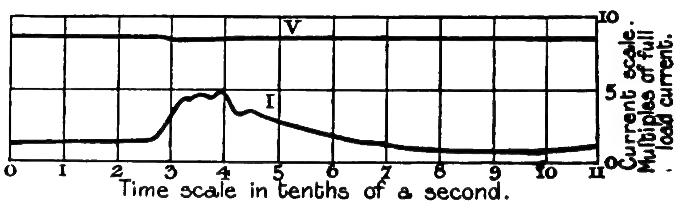


FIG. 3.

Inductance in the line has the effect of retarding the growth of the current and so allowing time for the short circuit to clear, but it has been found that an effective choking coil for this purpose would be of prohibitive size and cost. Cut-outs operate too slowly to be protective.

A most effective preventive of flashing-over has been found by the author in the use of asbestos-faced wipers placed between the brushes and extending the full length of the commutator. With these wipers in position it was found to be impossible to produce a flash-over under the most extreme conditions of load and sparking. On short-circuiting the loaded generator a shower of flashes starting from the brush-tip, travelled over the surface of the commutator to the wipers, where they were instantly quenched. Fig. 3 is an oscillogram taken under these conditions, from which it will be seen that the maximum current reached is about five times that at full load.

A further advantage in the use of the wipers is that the surface of the commutator is kept quite clean and normal sparking reduced to a minimum. The only drawback to their use is that they retain the carbon dust, and after a time become dirty. This results in some slight sparking under the wipers, particularly if set, as in this experiment, in the central position where the segments are carrying their maximum voltage. This points to the advantage of using thin wipers set close to the trailing tips of the brushes, and arranging them so that they may be easily cleaned or renewed.

The arrangement now used is to make the brush box double, the second compartment carrying the wiper. On the heaviest short circuit sparking is confined to the narrow space between the brush and the wiper.

Discussion.

Dr. W. M. Thornton: I had the idea of making some researches by means of the oscillograph into the question of flashing-over some years previously, and at that time I approached Messrs. Parsons with regard to experimenting on one of their machines, but as they did not seem anxious to run the risk of damaging valuable machinery the project fell through. At the same time, I held the theory that flashing-over was due to an inductive rise in pressure caused in the case of converters by the opening of the circuit breaker on a short circuit, but the author maintains that the lowering of the resistance of the path between the brushes, due to the formation of arcs between segments, is the real cause. It is a question which only the oscillograph can solve, and the latter is shown in the paper to be the correct explanation. Had the induction theory been correct, the flash in the case of a generator would follow the circuit breaker acting, and also generators would have been more liable to this trouble than motors, on account of the pressure piling up and finding a return path over the surface of the commutator. The proof of the correctness of the author's theory lies in Fig. 2, in which a distinct change in the running-up slope of the curve is seen at A, just previous to the flash taking place. It might be suggested that the effect could be minimised by having a resistance in parallel with the circuit breaker, but as the flash-over, in motors at least, usually commences before the breaker has time to act, it is obvious that nothing we could do to the circuit breaker could possibly have any effect in preventing the flash, though it might, by cutting off the supply, lessen the damage done. I believe with the author that the explanation is rather to be found in the maintenance of a true arc between segments than in the carbon dust theory alone, though there can be little doubt that disintegration of the brushes and possibly some local ionisation contribute to the result. The author's simple device, the efficacy of which we have all seen demonstrated, could be very readily applied in practice, and in the form shown would cost little in attention and renewals. Dr. Thornton.

Professor D. Robertson (*communicated*): I would like to ask the author whether the statement given at the foot of page 878 regarding the effect of the original brush position is put forward as a direct result of his experiments, or as his opinion of what he would find if he tried it. His explanation of the cause of the flash-over is a very likely one in many cases, as it is not an uncommon occurrence with some kinds of carbons to see a red spark, *i.e.*, not an arc, carried round the commutator, even when there is no appreciable sparking at the brushes. I do not think, however, that disintegration of the brushes Professor Robertson.

Professor Robertson.

is at all necessary. Overload produces sparking, which is the more violent the less load the brushes have. These sparks are nothing but small arcs from the brush to the segment, and may easily bridge from segment to segment if not quenched in time. In the ordinary way they are put out by cooling below the temperature at which the air is a good enough conductor, but if they are not extinguished in time a succession of them may produce an arc from brush to brush. The higher the speed of the machine the less the time for which the arc must last before it can be drawn from brush to brush and the more likely will flashing occur. Also, the more energy the current supplies to the arc—*i.e.*, the higher the voltage between the segments—the hotter the segments and surrounding air are, and the lower the barometric pressure the longer will the arc between the segments be maintained and the greater the risk of its reaching too far. The voltage between the segments at the departing edge of the brush, which maintains the arc as the segments leave the brush, is raised in a motor and lowered in a generator by the armature reaction; hence the greater danger with the former. With rotaries the matter is complicated by the oscillations of flux produced by hunting, and they are made worse by the fact that the converter may act as an ordinary generator after the alternating-current supply is cut off, when its commutating conditions are worse than those of a standard generator. Can Mr. Firth say from his experience whether the flash-over with a converter occurs before or after the circuit breaker on the alternating-current side has done its part? In any case, sparking before the overload occurs heats the commutator and consequently increases the risk of the flash-over. The oscillograms given in the paper are very instructive and fully confirm the author's opinion as to the instant that the flash-over commences. The speed of the machine is not given, but it is probably not far from 1,200 revs. per minute, in which case a quarter turn of the armature would take $\frac{1}{80}$ second. The time elapsing between the commencement of the overload and the sudden rise of current is of this order and is therefore consistent with an arc, or a series of particles, being carried from brush to brush to start it.

Mr. Stoney.

Mr. G. STONEY: I think Mr. Firth is to be congratulated on his experiments, and I am only sorry that it was not possible to carry out Dr. Thornton's experiments as proposed. Flashing-over occurs, as I have always thought, without rise of voltage, and it is also liable to occur when the maximum voltage per segment is high, or the pole-tips are badly shaped, and also where the armature reaction is considerable. Attention to these points in design and the provision of thicker mica between the commutator segments helps to obviate flashing over. Another point worth considering is that 4-pole machines are much more liable to flash over than 2-pole machines. This is probably due to the interchange of current between the sections of the windings. We tried wipers about ten years ago, but we were convinced that they were not practicable, and I do not think it is feasible to fit them on commercial machines.

Mr. W. BAXTER: I think that the leakage field has a good deal to do with starting the flash on its journey away from the commutator, and also in eventually blowing it out. I have seen some very severe flashes on generators, and if they are any more immune than motors it is probably due to the fact that a designer usually ensures that the sparking constants are better. I agree with the author that a rise in voltage is not the cause of flashing, but not with his calculation as to the voltage necessary to flash over all the mica segments, because, while this might be correct for a perfectly clean commutator, a very much lower voltage is sufficient to flash right round a commutator which has been working for some time. I do not agree that any one set of brushes is specially liable to flash, and in any case gravity can have nothing to do with it because on this particular machine, running at 1,500 revs. per minute, the force of gravity is only about 1 per cent. of the centrifugal force. I think that wipers are good enough on gas engines and machines of that sort, but they are out of place on electric motors, and it would be extremely difficult to sell machines fitted with them. Machines designed to carry 100 per cent. overload sparklessly would not give much trouble due to flashing over. Mr. Baxter.

Mr. J. SCHUIL: There is no difficulty in making any ordinary motor spark over. Even a 2-pole machine will do so if the excitation is reduced sufficiently, sometimes even unloaded. On a machine with commutating poles the excitation may be almost reduced to zero as these poles will prevent the machine from flashing. On the other hand, we may get an incandescent point formed by carbonisation of the mica between the segments to run right from brush to brush without causing a flash-over. That in a well-designed' machine the maximum voltage per segment may be very high is proved by some 2,000-volt machines made by Messrs. Brown-Boveri & Co., in which the maximum voltage per segment is 52 volts. It seems to me that these facts prove that the cause of flashing over is not so much the pressure of dust on the commutator as faulty design, and that the remedy lies in providing the right conditions at the point of reversing. Referring again to the Brown-Boveri machines, I believe that to effect commutation they provide a carbon brush with a copper brush leading separated by a sheet of asbestos and electrically connected by a resistance. The width of the brushes is such that they cannot touch two segments at the same time. I have noticed very often that sparking over is caused by high mica on the commutator. This is especially so with new machines, as the heating of the commutator causes it to expand, and on cooling the mica does not contract. If such a machine is not hourly attended to, it will spark very badly and easily flash over. I had such a case a few weeks ago, the machine flashing over whilst I examined the commutator. In some of the earlier electrical company's motors of the **S** type made with ring armatures the field had a lot of iron, and as they had a very small shunt current they could be run almost without excitation without flashing. In the present design of drum armatures the amount of iron is cut very Mr. Schuil.

Mr. Schuil. low, tending also to make them flash over easily. Referring to Mr. Burgess's remarks on the use of condensers to extinguish the spark, I may say that I have recently made some experiments with condensers for direct current, and found that they are very unsatisfactory for overloads; in fact, I found that a condenser which would prevent an arc when breaking 22 amperes would show no effect at all with 25 amperes. This test was repeated several times. Electrolytic condensers are not suitable for direct current.

Mr. Keelan. Mr. R. E. KEELAN: The author in his paper attributes the cause of flashing over to an accumulation of conductive particles on the surface of the commutator, between two brushes of opposite polarity. There is no doubt that in many cases this is the cause, but I should like to state that I have noticed several cases of bad "flashing over" in which the author's reason—*i.e.*, a dirty commutator—has been entirely absent. One case in particular that has come under my notice was that of a 500-volt self-excited shunt generator, which had never been previously run, and had a perfectly clean surface, and yet flashed when running on open circuit; the initial sparking was caused by the brushes being a little out of the neutral zone. Being anxious to find out the cause, I left the brushes in the above-stated wrong position, and started the machine from rest, with no resistance in the shunt field circuit—*i.e.*, with full shunt and with a voltmeter connected across the brushes. I found that immediately the machines reached a voltage of 550–600 volts it flashed over; on shutting down the commutator surface was found to be quite clean, except for the blackening of the surface due to the arc. I would suggest the following explanation: At the moment the violent sparking occurs—*i.e.*, at almost the same instant as that of flashing over, the excessive current in the coil which is short-circuited by the brush causes the brush-tips to become almost incandescent, and thus ionises the thin layer of air, which tends to revolve in the same direction as that of rotation of the armature, due to the skin friction of the commutator surface; it thus considerably reduces the resistance of the atmospheric path between the two adjacent brushes. I think that the author's arrangement of fixing asbestos guards and wipers on the brushgear is effective, not so much by reason of its keeping the commutator clean as by destroying this thin layer of revolving air. This, coupled with the inertia of the spark due to the speed of the commutator, tends to break down the resistance, prolongs the already existing spark—the maintenance of which is also assisted by the gradually increasing voltage between the individual segments as the armature conductors travel through the polar arc—and results in a flash-over. Flashing over is often well marked with machines fitted with interpoles, especially when the voltage per segment is high; and when the machine is subjected to a large and sudden fluctuation of load or short circuit, owing to the strong distortion of the flux thus produced, which is accentuated by the interpoles, an enormous potential difference between adjacent segments is set up, which frequently causes a flash-over. As a remedy for this

trouble a compensating winding is needed, such as is used in turbo-generators and rolling mill machinery. Mr. Keelan.

Mr. W. A. A. BURGESS: The trouble of flashing-over appears to me to be wholly a question of design. Wipers are sure to give trouble when they become dirty, and I can hardly imagine these being used on a 600-volt traction motor. A strong current of air from a fan fixed inside the armature and arranged to be especially directed at the heel of the brush might make a fairly good job, but at the same time I think the prevention of flashing should be prevented by designing the machines to suit the load. I would like to know if the author or any other member has tried the means Mr. W. A. Price uses for commutating his machines. It appears to me that it could be done with an ordinary direct-current commutator machine in just the same way. Mr. Price, in a demonstration of the capabilities of his machine before this section, drew attention to the fact that a current of any magnitude can be Mr. Burgess.

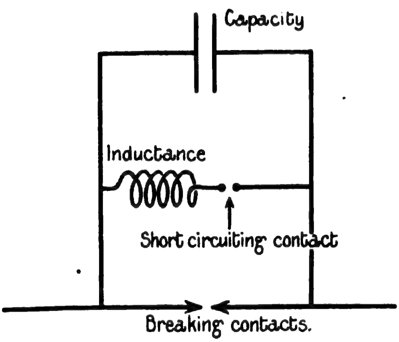


FIG. A.

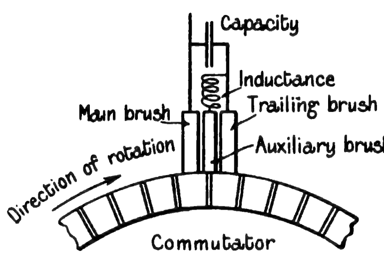


FIG. B.

successfully broken in air without sparking if a suitable condenser is shunted across the break. In applying this to a commutator and using an electrolytic condenser of the aluminium cell type, this being formed to give the largest capacity obtainable for a given size, and having also the advantage of a definite breakdown pressure and an equally definite sealing action, he found that he still got sparking at the moment when a brush bridged two segments, this being due to the discharging of the condenser. To get over the difficulty, he arranged an auxiliary contact in such a manner as first to short circuit the condenser through a suitable inductance as shown in Fig. A. This was found to be quite satisfactory and efficient. A modification which has occurred to me consists in the application of this arrangement to an ordinary commutator (Mr. Price's being of a very special nature), and is shown in Fig. B. A main current-collecting brush is provided with an auxiliary trailing brush to which it is connected through a suitable capacity, both brushes being narrower than one commutator segment. Between these two brushes

Mr. Burgess. and insulated therefrom by a thin layer of mica or fibre is placed a very thin brush connected to the trailing brush through a suitable inductance, and the brushes are so spaced that the coil circuit can only be broken when shunted by the condenser, and the condenser can only be short-circuited initially through the inductance. This arrangement is not put forward as a substitute for the known forms of commutation, or even as an alternative to commutating poles, but rather as a means of improving commutation where it cannot be obtained sparklessly by the usual means, and more particularly, perhaps, as a means of removing the prejudice against alternating-current commutator machinery. The point to be guarded against above all others in adopting the above device to improve commutation as a means of preventing flashing over, is the coincidence of the frequency of the break with the natural frequency of the auxiliary condenser-cum-inductance circuit which is a condition of perfect resonance. I would also like to know if any one has had experience with electrolytic condensers across the brushes, and if any results have been obtained.

Mr. Firth. Mr. FIRTH (*in reply*): In reply to Dr. Thornton, I may say that if the theory put forward in the paper is the correct one a circuit breaker which operated in a shorter time than that required for the commutator to turn through a brush spacing would be an effective safeguard against flashing over. The motor used in my experiments flashed over more frequently when copper fuses were used to short-circuit the generator than when the quicker-acting tin fuses were employed.

With reference to Professor Robertson's question, the statement respecting the effect of the original brush position is not the result of experiment, but is suggested by the fact that initial sparking is the usual preliminary to a flash-over. No experiments were made on converters, as the machines available were of too low a voltage to give the effect.

As regards Mr. Stoney's remarks, I think the reason that multipolar machines are more liable to flash over than bipolars is that, generally speaking, the time of movement of a segment from brush to brush is less in the former than in the latter. It would be interesting to know exactly why the wipers were unsuccessful in his machines.

In reply to Mr. Baxter, the arc theory of the paper sufficiently well explains why motors are more subject than generators to flashing over without attributing it to less careful treatment on the part of the designer. The calculated flash-over voltage is for a clean commutator; but it would be of the same order of magnitude for a commutator after use. I think there is sufficient margin between the calculated values—viz., 49,500 volts and 248 volts—to disarm any criticism on that point. It is impossible to calculate even approximately the centrifugal force acting on a particle when liberated from the brush. At the instant of release the particle is at rest and probably never attains the speed of the surface of the commutator. Moreover, at the lower brushes centrifugal force never comes into action, because the particles fall clear immediately they are released from the brush.

I know of no objection to the use of suitably designed wipers, and if they are effective for their purpose no one should hesitate about buying machines fitted with them on account of their appearance. Mr. Firth.

If Mr. Keelan will refer to the paper as read he will find that the presence of dust is not regarded as essential. The case he quotes is explained by the local arc theory. There may be some truth in his suggestion that a layer of ionised air is formed on the surface of the commutator; but it is not a necessary one. The function of the wipers is more probably to remove the small arcs mechanically.

1,200-VOLT TRACTION IN THE UNITED STATES OF AMERICA.

By T. STEVENS, M.E., Member.

(*Paper received 16th January*, 1912.)

Under the Board of Trade Regulations, which are reasonable, tramways have in Great Britain long since shown what is the limit of the distance from feeding-point that can be worked for any service.

Obviously doubling the supply voltage approximately halves the current for any traction unit and doubles the distance the earthed return can carry a definite amount of current without exceeding the 7-volt rule.

Conditions in America are so unlike those in England that direct comparisons are not always applicable, but the use on railways of double the usual supply voltage has been sufficient to render some of the results of a recent inspection and study of this subject of interest to those dealing with tramways and railways.

Plans of lines so equipped in the United States accompany this abstract. These have been drawn to a uniform scale except in the case of the Southern Pacific Company's electrified suburban section, which requires the larger scale specified in Fig. 3 to show it clearly.

The service for which any system was originally designed is seldom that actually run, but the services actually being run when this data was collected have been studied and are partly shown plotted for the busiest morning hours, together with diagrams of the respective feeder systems from sub-stations, the distance scale in the time table being identical with the scale of the plans.

There are 12 systems enumerated in Table I., using 1,200 volts. In every case multiple unit control is used, and all cars are equipped with the straight air brake system.

In most cases the cars collect at some part of their routes from 600-volt contact wires in addition to collecting from 1,200-volt contact wires in the parts of their routes shown in the plans.

Four motor equipments are used in every case. Each motor has 600 volts across its terminals on the 1,200-volt supply, and 300 volts on the 600-volt supply—*i.e.*, the two motors are permanently in series—with the

List of 1,200-volt Traction Systems in Service in U.S.A.

Name.	Approximate Location.		Opened for Service.	Miles Route. 1,200 Volts.	Miles Single Track, 1,200 Volts.	Miles Route, 600 Volts.	Sub-stations.	
	Longitude.	Latitude.					No.	Rated Kilowatts.
1. Aroostook Valley Railway, Presque Island, Maine ...	68 W.	46¾ N.	February, 1910	14	—	None	None	—
2. Sapulpa and Inland Railway, Oklahoma	96 W.	36 N.	June, 1910	10½	18	5	None	—
3. Southern Cambria Railway Company, Johnstown, Pa.	79 W.	41½ N.	1910	11	24	Some	None	—
4. Southern Pacific Company, California	122 W.	37½ N.	1911	50	96	None	3	Twelve 750-k.w. rotaries
5. Milwaukee E. R. and L. Company	88 W.	43 N.	1910	—	75	23	1 3 1	1,500 k.w. 1,200 „ 1,000 „
6. Oakland and Antioch, California	121½ W.	37½ N.	—	—	25	Some	2	—
7. Central California, T. Company, Stockton, California	121 W.	37½ N.	1906	16	30	Some	—	Two 500-k.w. motor-generators
8. Indianapolis and Louisville	86 W.	39 N.	1907	41	41	Some	None	—
9. Shore Line, E.R. Company, Connecticut	72¾ W.	41¼ N.	—	52	52	Some	2	—
10. Meriden, Middleton, and Guilford	72¾ W.	41½ N.	—	—	20	Some	—	—
11. Washington, Baltimore, and Annapolis	77 W.	39 N.	15th February, 1910	60	80	Some	4	—
12. Pittsburgh, Butler, Harmony, and Newcastle ...	80 W.	41 N.	27th July, 1908	—	75	4	3	—
Approximate total miles					550			

TABLE II.

List of Rolling Stock.

Name.	Motor-cars.	Weight, Tons (2,240 Lbs).	Seats.	Motors per Car.	Horse-power per Motor.	Maximum Speed, Miles per Hour.
1. Aroostook Valley Railway	3	27	36	4	50	35
	1 loco.	32	—	4	75	—
2. Sapulpa and Inland Railway	7	—	—	4	50	40
3. Southern Cambria Railway	4	32	50	4	75	45
4. Southern Pacific Company	78	—	116	4	125	43
	77 trailers	—	116	—	—	—
5. Milwaukee E. R. and L. Company	15	—	—	4	75	45
	15	35·7	64	4	125	55
6 Oakland and Antioch	1	—	—	4	75	45
	1	—	—	2	75	30
7. Central California Traction Company	12	—	—	4	75	45
8. Indianapolis and Louisville	13	—	—	4	75	45
9. Shore Line E. R. Company	12	—	—	4	50	40
10. Meriden, Middleton, and Guilford	3	—	—	4	50	40
11. Washington, Baltimore, and Annapolis	40	38	—	4	75	50
	3	—	—	4	125	45
12. Pittsburgh, Butler, Harmony, and Newcastle ...	21	28½	46	4	75	50
Approximate total	228	—	—	—	—	—

TABLE III.

Radius of Distribution.

Name.	Maximum Distance Fed from a Sub-station.	Section of Contact Wire.	Feeders.		
			Length.	Section.	Material.
	Miles.	Square Inch.	Miles.	Square Inch.	
1. Aroostook Valley Railway...	8	0·16	None	—	—
3. Southern Cambria Railway	7	0·16	None	—	—
4. Southern Pacific Company (Alameda Section)	7	—	3 5 3	3·00 2·50 1·70	Aluminium Aluminium Aluminium
5. Milwaukee	14	0·16 (20 miles) 0·10 (48 miles)	68	0·62	Aluminium
7. Central California Traction Company ...	—	—*	—	—	—
8. Indianopolis and Louisville	20	0·16	10 20 4	0·40 0·24 0·16	— — —
11. Washington, Baltimore, and Annapolis...	8	2 × 0·16	63 19	0·10 0·27	Copper Aluminium
12. Pittsburgh, Butler, Harmony, and New-castle	15	0·16	7 20	0·39 0·59	Aluminium Aluminium

* 1,200-volt "third" rail, with under-surface contact on part of route and single catenary elsewhere.

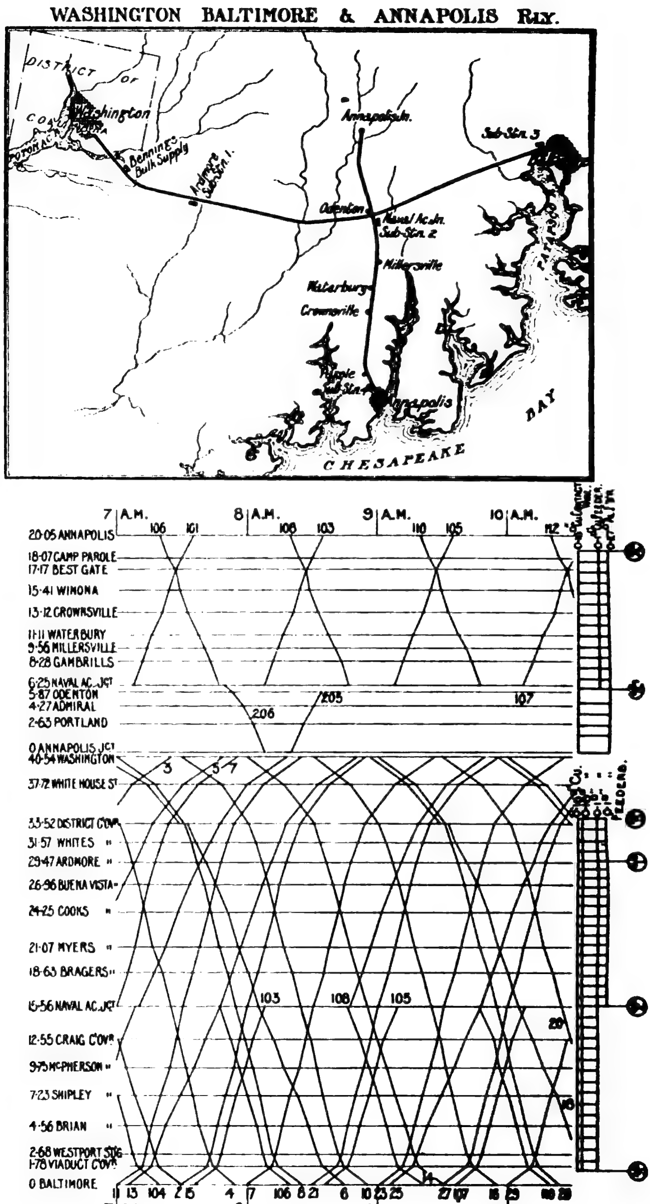

WASHINGTON BALTIMORE & ANNAPOLIS Rly.
DISTRICT OF COLUMBIA
Washington
POTOMAC
Bennings Bulk Supply
Ardmore Sub-Stn. 1.
Annapolis Jn.
Sub-Stn. 3
Odenton
Naval Ac. Jn. Sub-Stn. 2
Millersville
Waterbury
Crownsville
Annapolis
CHESAPEAKE
BAY
7 A.M.
8 A.M.
9 A.M.
10 A.M.
20·05 ANNAPOLIS
18·07 CAMP PAROLE
17·17 BEST GATE
15·41 WINONA
13·12 CROWNSVILLE
11·11 WATERBURY
9·56 MILLERSVILLE
8·28 GAMBRILLS
6·25 NAVAL AC. JCT
5·87 ODENTON
4·27 ADMIRAL
2·63 PORTLAND
0 ANNAPOLIS JCT
40·54 WASHINGTON
37·72 WHITE HOUSE ST
33·52 DISTRICT C'OV'R
31·57 WHITES
29·47 ARDMORE
26·96 BUENA VISTA
24·25 COOKS
21·07 MYERS
18·63 BRAGERS
15·56 NAVAL AC. JCT
12·55 CRAIG C'OV'R
9·75 McPHERSON
7·23 SHIPLEY
4·56 BRIAN
2·68 WESTPORT SDG
1·78 VIADUCT C'OV'R
0 BALTIMORE
FEEDERS.

FIG. I.

exception of a single line where 1,200-volt motors are used. Of course, insulation for 1,200 volts is necessary in every case.*

WASHINGTON, BALTIMORE, AND ANNAPOLIS 1,200-VOLT LINE.

The Graphic Time Table in Fig. 1 shows part of the Washington, Baltimore, and Annapolis service (No. 11, Table I.), and Table IV. summarises one whole day's running.

* One inter-urban company was installing double-throw switches to enable them to cut two of the four motors out of circuit at such times as they were taking current from an overloaded city 600-volt system, leaving two motors each receiving the maximum available voltage to drive a car. Electrolysis has been the subject of especial study in this case. One test showed pipes returning 38 per cent. of 12,000 amperes output from power house. The maximum positive pipe potential before 1905 was 24 volts. By the addition of return feeder cables and extra bonding, this has been reduced to under 2 volts. This work was described by Messrs. Lampher and Smith before the Engineers' Society of Western Pennsylvania on 20th June, 1911.

FIG. 2.—Voltage Drops in Overhead Contact Wires, Feeders, and Rails.

The straight lines show average drops over the working day and time table.
The full curves are based on 3·9 k.w.-hours per car-mile, 35 miles per hour average, 48 miles per hour maximum.
The dotted curves are based on instantaneous values under maximum load conditions in Fig. 1 which are at the times stated.
Single cars only. The figures stated refer to rail drops.

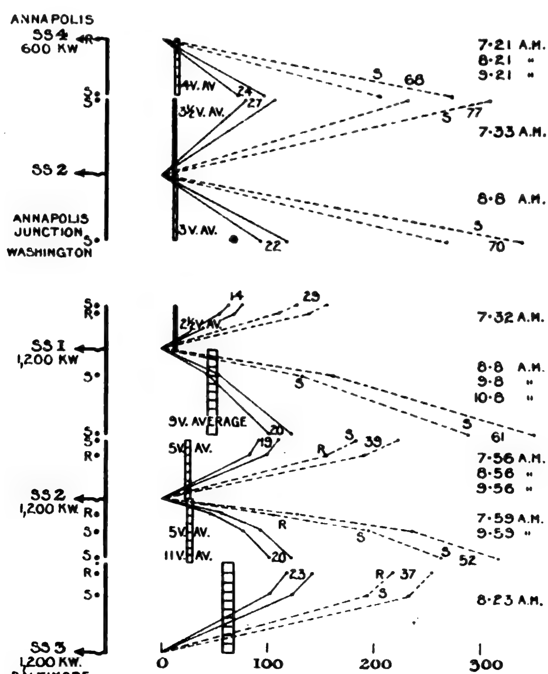


TABLE IV.

Washington, Baltimore, and Annapolis Railway.

Train-miles per day (April, 1910, Time Table).

Sub-station Number.	1.	2.		3.	4.
Distance northwards (miles)	8·19	5·71	—	1·30	—
Distance southwards (miles)	4·26	5·61	—	8·45	—
Distance eastwards (miles)...	—	—	6·87	—	0·85
Distance westwards (miles)	—	—	6·25	—	6·08
Route miles supplied	12·45	11·32	13·12	9·75	6·93
Number of stops	5	4	4	5	4
Average distance run (miles)	2·49	2·8	1·6	1·95	1·73
Schedule speed (maximum miles per hour) ...	47	48	32	25	32
Schedule speed (minimum miles per hour) ...	30	30	21	19	30
Train miles per day	—	1,152	296	—	—
Train miles per day per sub-station	1,147	1,448		1,081	250
Total miles per day				3,926	

SOUTHERN PACIFIC Co - OAKLAND ETC.

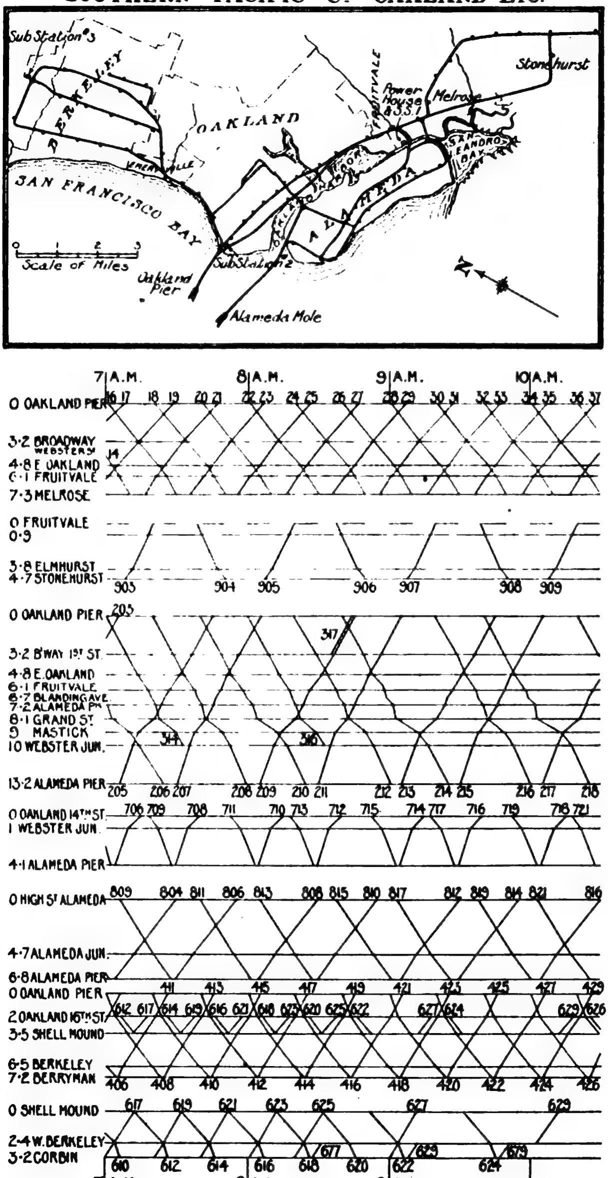


FIG. 3.

Three-phase bulk supply is delivered from Benning's power house at 6,600 volts to sub-station No. 5 (4 miles from Washington terminus). At sub-station No. 5 it is stepped up to 30,000 volts, whence transmission lines in duplicate run 35 miles. At 7 miles out both transmission lines are tapped off between pairs of isolating switches in each cable to sub-station No. 1, thence 13¾ miles to Academy Junction with similarly arranged tappings to two sub-stations—viz., No. 2 at this junction, and through 0·1 sq. in. single set 14 miles to Annapolis sub-station No. 4.

The duplicate transmission proceeds from the junction 14 miles on to sub-station No. 3, which is not far from the point where the 1,200-volt supply ends, and the run into Baltimore is continued on 600-volt city supply. At the other end the cars run 7 miles on 600-volt Washington city supply.

The contact wires shown in Fig. 1 are two in number from Washington to Baltimore, and single from Annapolis to Annapolis Junction. At Academy Junction the contact wires are provided with six switches on poles, so that any of the four branches or the crossing within the six switches can be isolated or fed from either direction.

The connections between 1,200-volt feeders and contact wires are indicated. These are 1 mile apart.

Southern Pacific Company.

The largest suburban system is the Southern Pacific Company's (No. 4, Table I.), for which the steam service (1st March, 1910) then to be superseded is plotted in Fig. 3 to the same scale as other graphic time tables. (The plan is to the larger scale stated.) From one to twelve cars are run in a train from each of two piers, served by ferry boats from San Francisco, which is 4 miles away. The lines are all through streets in residential suburbs.

The power house is planned for four 5,000-k.w. turbo-alternators supplied from water-tube boilers fired with crude petroleum. Three-phase 25-cycle 13,000-volt current is generated. The preliminary estimate for loads was:—

	Peak Load.	Average Kilowatts.
Power house, Fruitvale	15,000	8,700
Sub-station No. 1, Fruitvale	3,800	1,800
Sub-station No. 2, West Oakland ...	7,200	4,000
Sub-station No. 3, North Berkeley ...	3,400	1,700

FIG. 4.

Duplicate sets of transmission lines, following distinct routes, feed sub-station No. 2 and continue on to No. 3. In these sub-stations 3-phase transformers step down to 440 volts for supply to rotary converters that furnish direct current at 1,200 volts. Two 750-k.w. 600-volt converters are mounted on one base, connected two in series and insulated from earth.

The overhead trolley system is of the single catenary form of construction with messenger hanger supports spaced 15 ft. apart. Under

TABLE V.

Southern Pacific Company's Cars for Electrified Suburban Lines.

	Combination Coach.	Motor Coach.	Trail Coach.
Weight of car body only...	41,300 lbs.	41,300 lbs.	39,000 lbs.
Weight of electric equipment and air brake equipment on car body ...	13,800 „	13,800 „	3,800 „
Weight of trucks, frames, wheels, and axles ...	27,400 „	27,400 „	20,400 „
Weight of electric equipment on trucks	20,650 „	20,650 „	—
Weight of car complete	103,150 „	103,150 „	63,200 „
Seating capacity	89	116	116
Length over buffers ...	68 ft.	73 ft.	73 ft.
Width of car over all ...	10 ft. 6 in.		
Height from running rail to top of roof	13 „ 0 „		
Distance from running rail to underside of sills ...	3 „ 9 „		
Seat centres	28¾ „		
Truck	45 „ 0½ „		
Wheel base of car ...	52 „ 0½ „		
Wheel base of track ...	7 „ 0 „		

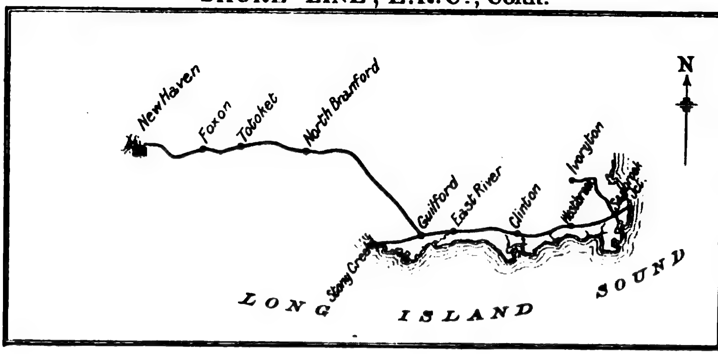
normal conditions the trolley system is connected in solidly by jumpers and switches around section insulators.

Fig. 4 shows a photograph of the construction leading to the landing-stage.

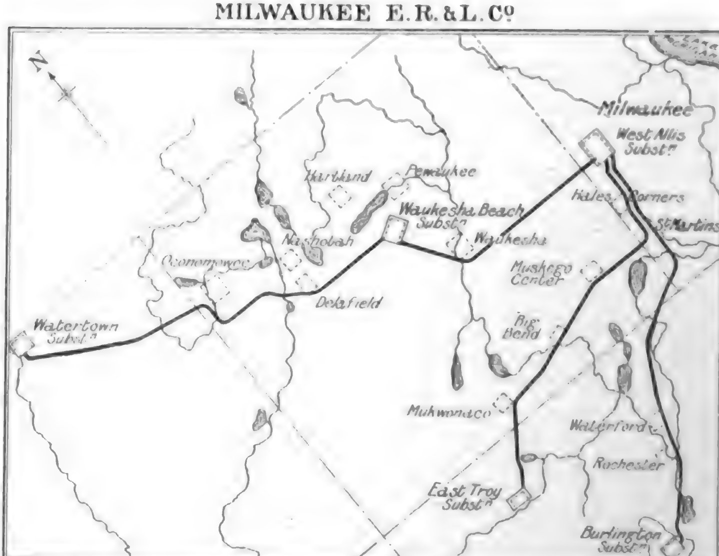
The population served is approximately 250,000. The estimated consumption of energy was 83 watt-hours per ton-mile. The maximum speed of a train made up of one motor-car and one trail-car is 42 miles per hour.

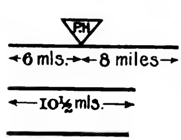
Passenger Fares.—Generally the fares charged are 10 cents (5d.) from San Francisco to any point shown on the map (Fig. 3), except to

SHORE LINE, E.R.C°, Conn.



MILWAUKEE E.R.&L.C°





Aroostook Valley R.

Sapulpa & Inland R.

S. Cambrian R.C°

FIG. 5.

Stonehurst, where 5 cents (2½d.) additional is charged between Fruitvale and that point. Season tickets ("commutation tickets") are sold, good for one round trip daily, at the rate of $3.00 (12s. 6d.) per month.*

	Southern Pacific Suburban Lines in Fig 3.	Illinois Central Suburban Lines within 20 Miles of Chicago.
Passengers in last financial year	25,000,000	28,000,000
Passengers in previous financial year ...	23,000,000	25,000,000

MILWAUKEE.

The 1,200-volt lines in Milwaukee suburbs are shown in Fig. 5 (which also shows four other plans to same scale). In winter there is an interval of 2 hours between trains in each direction. In summer this is reduced to 1-hour interval, and in busy hours each motor-car draws one or two trail-cars and even three trailers on holidays. The usual advertisement is "Your watch is the time table." The cars start from the Central terminus on the hour.

INDIANAPOLIS AND LOUISVILLE.

Fig. 6 shows a plan and graphic time table for the 1,200-volt section of the line between Indianapolis and Louisville.

PITTSBURGH, HARMONY, BUTLER, AND NEWCASTLE RAILWAY.

Fig. 7 shows similar details of Pittsburg, Harmony, Butler, and Newcastle Railway.†

A study of the value of 1,200 volts for interurban railways, presented to the American Institute of Electrical Engineers at Philadelphia, 10th January, 1910, by Mr. C. E. Eveleth, gave estimates for four representative types of American single-track lines of 100 miles each, and concluded that 1,200 volts is 10 per cent. to 20 per cent. cheaper in first cost, and 10 per cent. to 15 per cent. cheaper in operation and in maintenance, than 600 volts for same service.

For extensions in Great Britain, where it is necessary to consider 1,200 volts, we can only assume that the track will be single, with turn-

* *Passengers per Annum.*—The traffic (steam drawn) over the Southern Pacific Company's suburban lines shown in Fig. 3 is compared below with that over the Illinois Central lines running from 15 to 20 miles out of Chicago. The latter was chosen for this comparison because it is the heaviest suburban traffic in U.S.A. handled by a single company :—

† The Brescia Toscalano Railway line in Italy has a 1,200-volt overhead conductor. For its 33 miles of single track it has two sub-stations with accumulators ; 10 cars, each equipped with four 45-H.P. motors ; a 12-k.w. double-wound generator, seats for 50, standing room for 10 ; weighing 22 tons ; also one car with two 45-H.P. motors and a generator ; seats for 20, standing room for 10 ; weighing 9 tons.

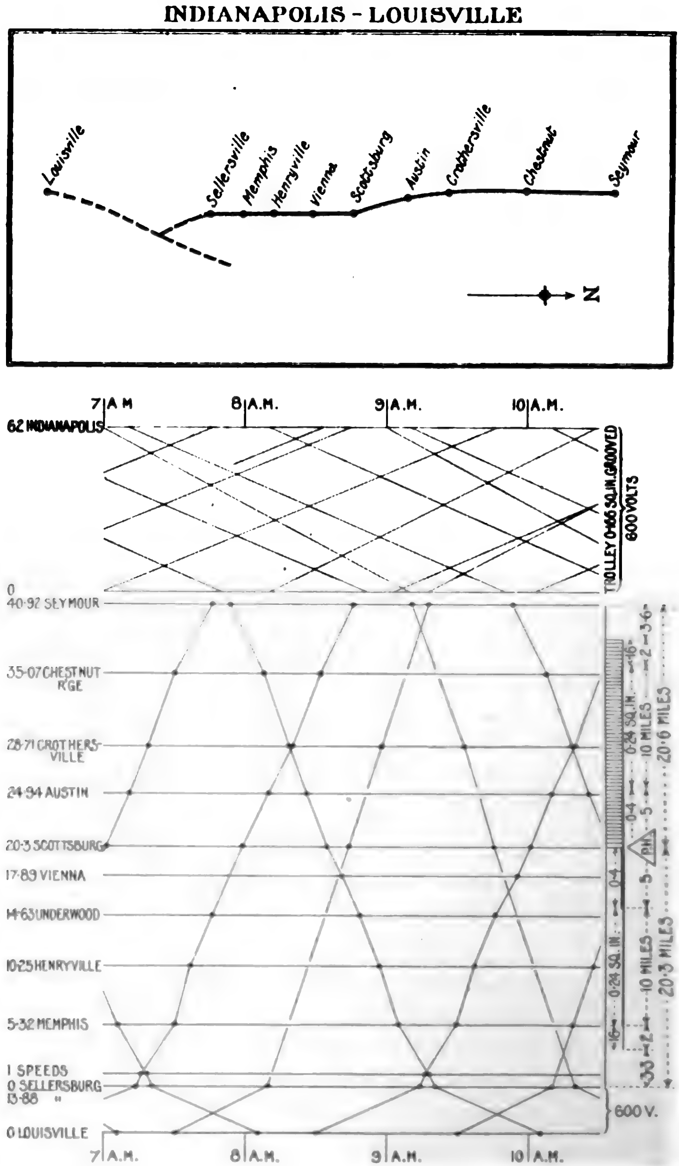

INDIANAPOLIS - LOUISVILLE
Louisville
Sellersville
Memphis
Henryville
Vienna
Scottsburg
Austin
Crothersville
Chestnut
Seymour
N
7 A M
8 A.M.
9 A.M.
10 A.M.
62 INDIANAPOLIS
0
40·92 SEYMOUR
35·07 CHESTNUT RGE
28·71 CROTHERS-VILLE
24·94 AUSTIN
20·3 SCOTTSBURG
17·89 VIENNA
14·63 UNDERWOOD
10·25 HENRYVILLE
5·32 MEMPHIS
1 SPEEDS
0 SELLERSBURG
13·88 "
0 LOUISVILLE
TROLLEY 0·166 SQ.IN. GROOVED
600 VOLTS
600 V.
10 MILES
20·6 MILES
10 MILES
20·3 MILES
0·24 SQ. IN.
0·24 SQ. IN.

FIG. 6.

Approximate Data of 1,200-volt Inter-urban Lines in U.S.A. (Total, 550 Miles.)

Group Number (see next Table). Length Limits of Group, Track Miles.	3. 11 to 20.	4. 21 to 30.	6. 41 to 96.
Number of undertakings	3	3	6
Average length (miles)	17	26	70
Average motor-cars owned per mile of track	0·27	0·23	0·47
Average miles of track per motor-car owned	3·7	4·3	2·1

TABLE VII.

Approximate 1910 Data of Electric Tramways in United Kingdom in Six Groups, according to Length.

Group Number. Length Limits of Group, Track Miles.	1. Under 6.	2. 6 to 10.	3. 11 to 20.	4. 21 to 30.	5. 31 to 40	6. Over 41.
Number of undertakings	66	54	38	10	8	10
Average length (miles)	3·5	8·3	15·5	24·6	35	65
Average cars owned per mile of track	3·6	3·5	3·7	3·2	5·1	7·3
Kilowatt average	260	500	1,200	1,500	3,200	9,400
Average miles of track per motor-car owned	0·28	0·29	0·27	0·31	0·20	0·14

outs of such length and locations that our cars will not interfere with each other.

The following is abstracted from an investigation of the value of doubling the supply voltage as a means of improving the profit margin in the earning capacity of prospective tramway extensions. They are useful in this abstract comparatively rather than separately, because

TABLE VIII.

Approximate 1910 *Data of Electric Railways in the United Kingdom in Groups according to Length.*

Group. Length Limits, Track Miles.	1. Under 6.	2. 6 to 10.	4. 21 to 30.	5. Over 31.
Number of undertakings	5	7	2	2
Average length ...	3·7	8	27	37

local conditions in any case have so considerable an influence on such calculated results that special study is essential in each case.

Table VI. groups together the 1,200-volt lines of similar lengths in Table I. Tables VII. and VIII. give corresponding data on electric tramways and railways in Great Britain.

TABLE IX.

Motor-cars per Mile of Track.

	1,200-volt Inter-urban Lines in U.S.A.	500-volt British Tramways.
	Cars per Mile.	Cars per Mile.
Under 20 track miles	0·27	3·5
21 to 30 track miles ...	0·23	3·2
Over 41 track miles ...	0·47	7·3
Total cars on all lines mentioned	228	11,560
Total track miles ...	550	2,450

These tables make it clear that it is not on lines comparable with British tramways that 1,200 volts has been adopted, but on lines with far less traffic density. With the traffic density on most British tramways there is less necessity for having so great a distance between substations in order that capital outlay may be well utilised. It must be

PITTSBURG BUTLER HARMONY & NEWCASTLE RLY.

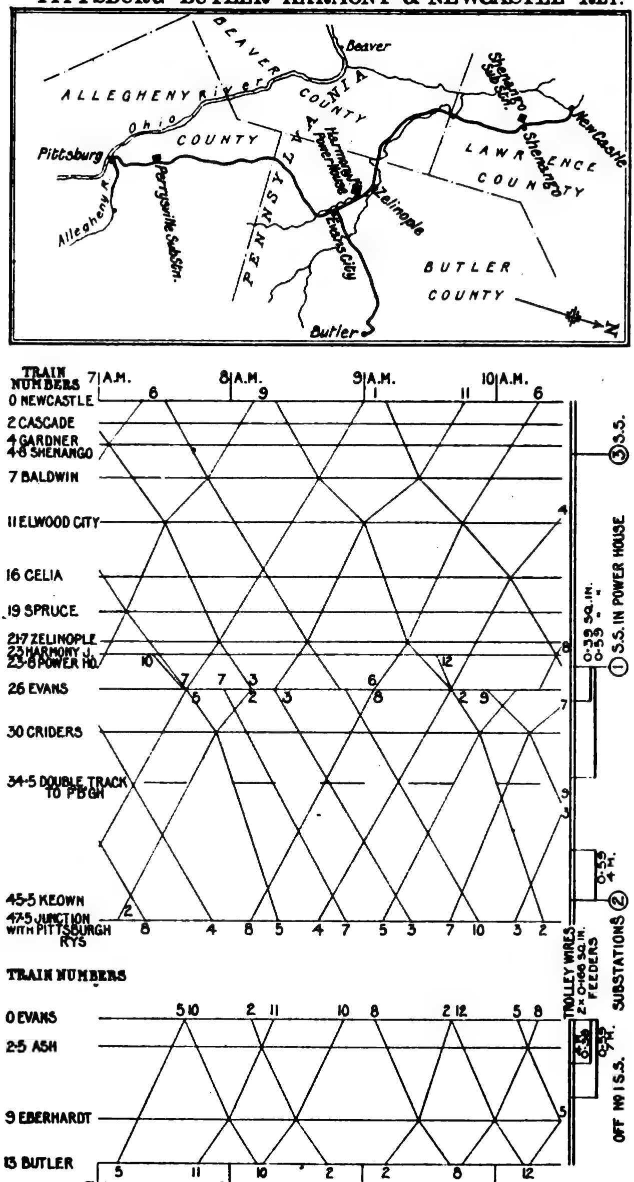


FIG. 7.

remembered that the "regulation 7-volt drop" limit in earthed return must not be exceeded in Great Britain, and this is more readily accomplished the higher the pressure. In America, as previously stated, there is no such specified limit.

Fig. 8 shows a part of a sample British tramway in plan and contact wire, feeder, and rail drop from A to G, neglecting the conductivity of the earth, with 500-volt power supply at A (*i.e.*, without sub-stations) and centre of traffic at C. The dots represent 16 cars running a 2-minute service between C and F, and 7 cars, 3-minute service F to G, with 1·6 k.w.-hours per car-mile average input. The distances are to scale, the last car is 3·6 miles from the power house and 2·3 miles from the boosted rail return feeding-point at E.

The broken and dotted lines indicate positive feeders 3·5 sq. in. section between A and C, 0·75 sq. in. between C and F, 0·25 sq. in. C to I. From A to G double tracks with two contact wires of 0·166 sq. in. section are in use.

The supply to 13 cars running 3-minute services I to J and J to K, also 4 cars on 1½-minute service C to I, and 2 cars on 5-minute service C to H, and 1 car A to C, contribute their quota to these drops.

Fig. 9 gives drops on a hypothetical 1,200-volt installation over a route of 6 miles with 4 cars running on 15-minute service at 16 miles per hour. With half-mile runs the consumption of energy is 1·4 k.w.-hours per car-mile and 6·6 volts rail drop.

In the case shown in Fig. 12 the pressure is again 1,200 volts, with the same length of line as in Fig. 8, but with a 4-minute service and 12 cars running at 10 miles per hour and quarter-mile runs. The energy consumed is 1·6 k.w.-hours per car-mile with 7 volts maximum in rail return.

Fig. 10 is based on average data of a number of British tramways fed from *sub-stations* 4 miles apart on the average, with various services; the average car weighs 14 tons with two-motor equipment and runs at 10 miles per hour with 4 minutes headway, consuming 1·6 k.w.-hours per car-mile. For two overhead copper contact wires each 0·1 sq. in. section, 0·213 ohm per mile at 20° C. and for rail return 0·03 ohm per mile. The average drops in 500-volt contact wires and rails are shown in Fig. 10, and in addition the instantaneous drops are shown assuming two cars starting with 100 amperes each and three others running with average input and one standing. Alongside of these in Fig. 11 are shown results, not quite in proportion to the voltage, for 4 motor-cars weighing 17 tons with 12 per cent. higher car speed and 20 per cent. higher energy consumption per ton-mile and 43 per cent. higher energy consumption per car-mile. The contrast between Fig. 11 relating to 1,200 volts at the sub-stations and Fig. 10 relating to 500 volts at the sub-stations is striking.*

* Level, 1 mile per hour per second acceleration, 1·5 retardation, 50 seconds coasting in each half-mile run, motor characteristics assumed same for both cases. It is evident that special insulation would be necessary for the 1,200-volt equipment.

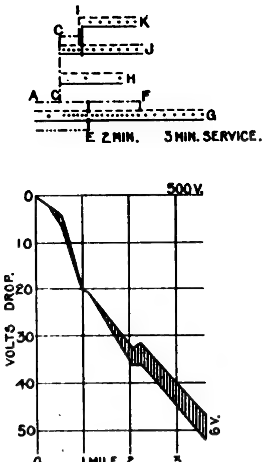


FIG. 8. PART OF A TYPICAL BRITISH TRAMWAY.
POWER HOUSE AT A.
43 CARS ON THIS SECTION.
DROPS FROM A TO G 24 CARS.

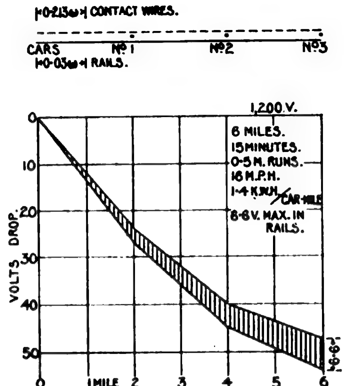


FIG. 9.

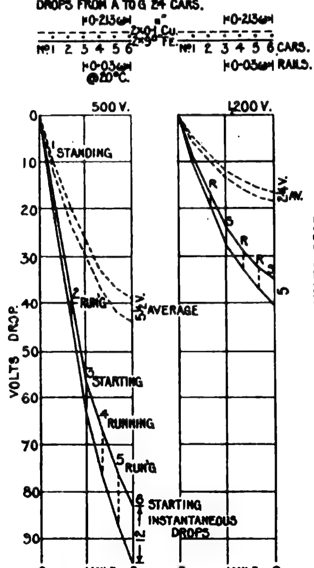


FIG. 10. 500 V.
FIG. 11. 1,200 V.

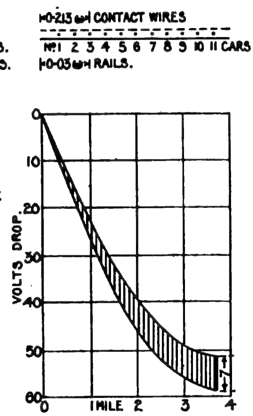


FIG. 12. 1,200 V.

DROPS IN VOLTS IN CONTACT WIRES & RAILS.

2 MILES.
4 MINUTE SERVICE.
10 M.P.H.
1·8 K.W.H./CAR-MILE.
5½ V. IN RAILS. 2¼ V. IN RAILS.

3·6 MILES.
4 MINUTES 0·25 MILE RUNS.
10 M.P.H.
1·6 K.W.H./CAR-MILE.
7 V. MAX. IN RAILS.

FIGS. 8–12.

Referring again to the graphic time table, Fig. 1, showing part of the Washington, Baltimore, and Annapolis service, to show how American average drops and instantaneous maxima compare with British practice, Fig. 2 has been plotted, assuming *single* cars running at the times stated. It must be understood that the actual service is a single car service during slack hours only. There were no vested interests there before the electrification that required considerations of a 7-volt drop in an earthed return to enter into their calculations. This 7-volt limit is quite reasonable where it is applied in this country, and means only, if exceeded, some one is willingly assuming the responsibility for consequential damages. Our calculations assume the rails carry all the current, *i.e.*, we neglect the earth's conductivity. Three "drops" are shown, viz.:—

1. Drop in contact wire and feeder, also rails, averaged over service hours for service time table (Table IV., page 896);
2. Values with average input; and
3. Instantaneous values with single cars starting at points "S" and single cars running with average input at points "R," which correspond with the largest demands in graphic time table, Fig. 1.

Appreciation is expressed of courtesies extended and information given by A. H. Babcock, Esq., Electrical Engineer, Southern Pacific Company; H. Etheridge, Esq., Superintendent, Pittsburgh, Butler, Harmony, and Newcastle Railway; C. E. Eveleth, Esq.; A. P. Gould, Esq., President, Aroostook Valley Railway; J. R. Hewett, Esq.; H. M. Hobart, Esq., Consulting Engineer; R. V. Miller, Esq., General Manager, Sapulpa and Inland Railway; F. R. Newman, Esq., General Manager, Southern Cambria Railway; J. N. Shanahan, Esq., Vice-President and General Manager, Washington, Baltimore, and Annapolis Railway; and A. W. Sperry, Esq., Engineer, Shore Line E.R. Company.

INDEX TO VOL. 48.

1911-12.

EXPLANATION OF ABBREVIATIONS.

(P) indicates a reference to the author and title of a Paper.

(D) indicates a reference to remarks made in a Discussion upon a Paper, the title of which is quoted.

Note.—The lists of speakers in the Discussion upon any Paper will be found in the Table of Contents at the beginning of the volume.

A.

B.

C.

D.

E.

F.

G.

H.

I.

J.

K.

L.

M.

S.

T.

U.

V.

W.

Contractors for Advertisements:
Walter Judd, Limited, 5, Queen Victoria Street, Mansion House, E.C.

UNWIN BROTHERS, LIMITED, THE GRESHAM PRESS, WOKING AND LONDON.